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## Asia Pacific Economic and Management Review

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# A Study on the Spatio-Temporal Characteristics and Spatial Differentiation of the Development Efficiency of China's Digital Cultural Industry

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**Abstract:** Under the national digital cultural strategy, it is crucial to systematically evaluate and continuously track the development efficiency of China's digital cultural industry. This paper constructs a global super-efficiency EBM model that considers non-expected outputs, empirically measures the development efficiency of China's digital cultural sector from 2011 to 2023, and uses the Moran index and Dagum Gini coefficient methods to comprehensively and deeply reveal the temporal and spatial characteristics and spatial differentiation of China's digital cultural industry development efficiency. The study finds that: (1) The overall efficiency of China's digital cultural industry is relatively low, with an average efficiency of 0.35, exhibiting a typical "V"-shaped distribution across different periods, and the eastern region significantly outperforms other areas. (2) The global Moran index shows a fluctuating downward trend overall, with a "Λ"-shaped distribution across different periods, and the local Moran index reveals that its spatial distribution is primarily concentrated in "H-H" and "L-L" clusters. (3) The overall disparities exhibit a fluctuating upward trend, with inter-regional disparities being the dominant factor, accounting for an average contribution rate of 38.50%. This study aims to promote the high-quality development of China's digital cultural industry by providing valuable references for future policy-making and decision-making.

**Keywords:** Digital Cultural Industry; Development Efficiency; Spatiotemporal Characteristics; Spatial Differentiation

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## Introduction

Digital cultural industries are a new type of industrial form that is driven by the national cultural digitization strategy, based on information technology, and centered on cultural creative content, achieving a high degree of integration between digital technology and the cultural creative content industry. To promote the prosperity and development of the digital cultural industry, China has issued and implemented a series of guiding policies and guidelines since 2011, and the logic and innovation path of digital cultural industry policies have become increasingly clear <sup>[1]</sup>. Under the guidance of national macro policies, the scale of China's digital cultural industry market has continued to expand. According to data from iiMedia Research, in the first three quarters of 2024, China's digital cultural revenue reached 4.16 trillion yuan, accounting for 41.8% of the total revenue of the cultural industry. Compared with the same period in 2019, the two figures increased by 2.1 times and 18.9 percentage points respectively <sup>[2]</sup>, highlighting its important contribution to the high-quality development of the

cultural industry. However, while the digital cultural industry is developing rapidly and upgrading its capabilities, it also faces challenges such as insufficient depth and richness of digital cultural product content, inadequate digital technology innovation, difficulties in determining the value of digital copyrights<sup>[3]</sup>, and uneven development of regional symbiosis<sup>[4]</sup>. Efficiency is one of the key indicators comprehensively reflecting the development level of the digital cultural industry, and it plays an important role in promoting the high-level development of the digital cultural industry and laying a solid foundation for building a “cultural powerhouse”.

A review of research findings on the evaluation of the digital cultural industry reveals that they are primarily divided into two categories: parametric methods and non-parametric methods. The former includes random frontier analysis (SFA) and semi-parametric estimation methods, which primarily focus on the evaluation of the cultural industry<sup>[5]</sup> and its input-output efficiency<sup>[6]</sup>. Among non-parametric methods, the DEA-Malmquist index method is widely applied. Scholars have used the BCC model to conduct an empirical analysis of the industrial investment efficiency of listed cultural enterprises<sup>[7]</sup> and have conducted an in-depth analysis of the input-output efficiency of the digital cultural industry from both dynamic and static perspectives<sup>[8]</sup>. Additionally, current research perspectives are increasingly focusing on the spatial dimension and paying attention to the evaluation of the development efficiency of the digital cultural industry in key regions. Research on the efficiency of digital cultural industry development in provinces and municipalities such as Beijing, Shanghai, Zhejiang, Jiangxi, Hunan, and Chongqing is increasingly abundant. Some scholars have proposed development suggestions from four aspects: digital cultural industry planning, talent teams, market entities, and security risks<sup>[9]</sup>. Others have conducted in-depth studies on the performance of digital cultural industry development and the mechanisms of influencing factors<sup>[10]</sup>. Additionally, some scholars have employed a three-stage DEA model to reveal that the efficiency of China’s digital cultural industry development exhibits regional differences and non-equilibrium characteristics<sup>[11,12]</sup>.

Existing research provides an extremely important reference value for this study, this paper employs the EBM model to calculate the efficiency of digital cultural industry development in 30 provinces of China from 2011 to 2023. Using the Dagum Gini coefficient and Moran index methods, it comprehensively and deeply reveals the spatiotemporal characteristics and spatial differentiation of China’s digital cultural industry development efficiency, providing valuable references for the high-quality development of China’s digital cultural industry and the construction of a modern industrial system in the next period. Therefore, the technical route studied in this paper is shown in Figure 1.

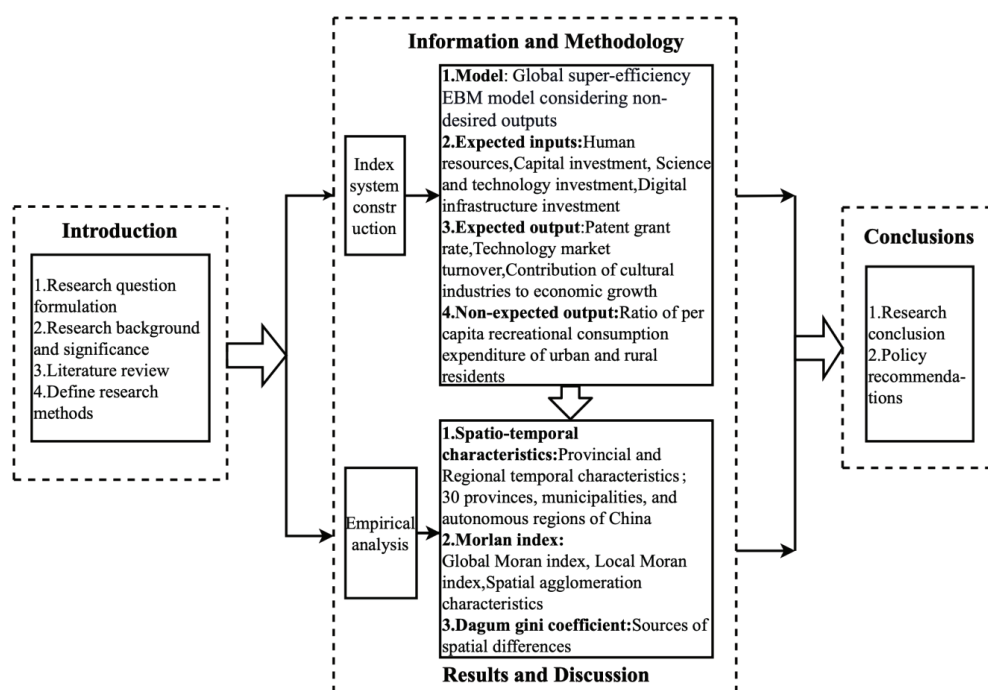


Fig. 1. The technical roadmap studied in this article

# 1. Model, Method, and Indicator Selection

## 1.1 Global Super-Efficiency EBM Model Considering Non-Desired Outputs

Constructing a production possibility set (PPS) is a prerequisite for measuring the efficiency of China's digital cultural industry development. This study adopts the global benchmarking method proposed by Pastor and Lovell <sup>[13]</sup> to expand the framework for global comparability in measuring the efficiency of China's digital cultural industry. Therefore, it draws on the super-efficiency evaluation method proposed by Tone <sup>[14]</sup> to compare the efficiency of DMUs in the digital cultural industry. Additionally, the measurement results of the efficiency of China's digital cultural industry development under constant returns to scale (CRS) and variable returns to scale (VRS) conditions differ significantly. Based on the views of Zheng et al. <sup>[15]</sup>, this study adopts the measurement results under the VRS condition. In view of this, under the condition of considering non-desired outputs, this paper aggregates all DMU<sub>j</sub> ( $j = 1, 2, \dots, n$ ) in all periods  $t$  ( $t = 1, 2, \dots, T$ ) to construct the global reference production possibility set:

$$PPS = \{(x^t, y^t) \mid x_i^t \geq \sum_{t=1}^T \sum_{j=1}^n \lambda_j^t x_{ij}^t; i = 1, 2, \dots, p; t = 1, 2, \dots, T;$$

$$y_r^t \leq \sum_{t=1}^T \sum_{j=1}^n \lambda_j^t y_{rj}^t; r = 1, 2, \dots, q; j = 1, 2, \dots, n; \lambda_j^t \geq 0\} \quad (1)$$

In the above equation (1),  $x$  represents factor inputs,  $y$  represents desired outputs, and  $\lambda_j^t$  represents the weight of the observed values of DMUs in period  $t$ . Therefore, based on the consideration of non-desirable outputs, the global super-efficiency value of the  $j$ th DMU can be calculated using Equation (2):

$$\gamma^* = \min_{\theta, \eta, \lambda, s^-, s^+} \frac{\theta + \varepsilon_x^- \sum_{i=1}^p \frac{\omega_{ij}^- s_{ij}^-}{x_{ij}}}{\eta - \varepsilon_y^+ \sum_{r=1}^q \frac{\omega_{rj}^+ s_{rj}^+}{y_{rj}} - \varepsilon_b^+ \sum_{e=1}^{q^*} \frac{\omega_{ej}^- s_{ej}^-}{b_{ej}^*}}$$

$$s. t. \quad \sum_{t=1}^T \sum_{j=1}^n \lambda_j^t x_{ij}^t - s_{ij}^- \leq \theta x_{ij}, i = 1, 2, \dots, p$$

$$\sum_{t=1}^T \sum_{j=1}^n \lambda_j^t y_{rj}^t + s_{rj}^+ \geq \eta y_{rj}, r = 1, 2, \dots, q$$

$$\sum_{t=1}^T \sum_{j=1}^n \lambda_j^t b_{ej}^t - s_{ej}^- \leq \eta b_{ej}, e = 1, \dots, q^*$$

$$\sum_{t=1}^T \sum_{j=1}^n \lambda_j^t = 1$$

$$\lambda_j^t \geq 0; s_{ij}^-, s_{rj}^+, s_{ej}^- \geq 0; j = 1, 2, \dots, n;$$

$$\varepsilon_x^- \geq 0, \varepsilon_y^+ \leq 1; 0 < \theta \leq 1; \eta \geq 1; t = 1, 2, \dots, T \quad (2)$$

Equation (2),  $\gamma^*$  represents the efficiency value of the evaluated DMU<sub>j</sub> as the optimal solution of the objective function,  $\theta$ ,  $\eta$  represents the radial model efficiency value and its reciprocal, respectively.  $x_{ij}$ ,  $y_{rj}$  and  $b_{ej}^t$  represent the original values of the inputs, expected outputs, and non-expected outputs of the evaluated DMU<sub>j</sub>, respectively. While,  $s_{ij}^-$ ,  $s_{rj}^+$ ,  $s_{ej}^-$  correspond to the input, expected output, and non-expected output slack values, respectively. The values of  $\omega_{ij}^-$ ,  $\omega_{rj}^+$ ,  $\omega_{ej}^-$  are all greater than or equal to 0, representing the weights of the input, expected output, and non-expected output factors, respectively.  $\theta$  is a key parameter in the EBM model, with a value range between [0, 1]. If  $\varepsilon_x^-$ ,  $\varepsilon_y^+$ ,  $\varepsilon_b^+$  = 0, it is equivalent to the radial CCR model; if  $\varepsilon_x^-$ ,  $\varepsilon_y^+$ ,  $\varepsilon_b^+$  = 1, it is equivalent to the SBM model.

## 1.2 Research methods

### 1.2.1 Moran Index

The Moran Index is an important indicator in spatial autocorrelation analysis, divided into global Moran Index and local

Moran Index, and widely applied in fields such as socio-economics, cultural ecology, and public services. This study employs the global Moran Index to empirically measure whether China's digital cultural industry development efficiency exhibits spatial clustering, dispersion, or complete independence, and further uses the local Moran Index to reveal any hidden local clustering areas. The specific calculation formula is referenced from Ma Yanyan et al. <sup>[16]</sup>.

### 1.2.2 Dagum Gini Coefficient

This paper adopts the Dagum Gini coefficient and its sub-group decomposition method <sup>[17]</sup> to empirically analyze the spatial differentiation of the efficiency of China's digital cultural industry development. Compared with the traditional Gini coefficient and Theil index, the Dagum Gini coefficient not only reports the overall efficiency gap of China's digital cultural industry development but also further decomposes it into intra-regional gaps, inter-regional gaps, and inter-regional hyper-diversity, thereby better identifying the spatial sources of efficiency differences in China's digital cultural industry development. The specific calculation formula is referenced from Zhang Hongfeng et al. <sup>[18]</sup>.

### 1.3 Indicator Selection and Data Description

Based on the Cobb-Douglas production function, this paper constructs a digital cultural industry development efficiency evaluation indicator system (Table 1) from the perspectives of inputs and outputs. Among the input indicators, the number of employees in the cultural industry at the end of the year is selected as labor input, the total assets of the cultural industry as capital input, internal R&D expenditure as technological input, and the number of internet broadband access ports as digital infrastructure input. In terms of expected output indicators, this paper starts from the value form of the digital cultural industry and selects patent authorization rate, technology market transaction volume, and the contribution of the cultural industry to economic growth as output elements of the digital cultural industry. Regarding non-expected output indicators, existing literature has rarely mentioned or analyzed them. Given that the industry expects the urban-rural gap in digital cultural industry development to be as small as possible, this paper selects the ratio of per capita cultural and entertainment expenditure between urban and rural residents as the non-expected output indicator. The above indicator data are sourced from the "China Cultural and Related Industries Statistical Yearbook" (2012~2024), "China Statistical Yearbook," and "China Science and Technology Statistical Yearbook." Considering the availability and completeness of sample data, this study takes 30 provinces in China (excluding Taiwan Province of China, Hong Kong Special Administrative Region of China, and Macau Special Administrative Region of China, as well as the Tibet Autonomous Region of China) from 2011 to 2023 as the research object.

Table 1: Descriptive Statistics of Variables

Indicator type	Indicator description	Mean	Standard deviation	Minimum value	Maximum value
Expected inputs	Human resources (people)	217313	316940	1681	1.837e+06
	Capital investment (ten thousand yuan)	3.810e+07	5.923e+07	520645	3.278e+08
	Science and technology investment (ten thousand yuan)	6.399e+06	7.866e+06	103,717	4.803e+07
	Digital infrastructure investment (ten thousand units)	2389	1948	62	10395
Expected outputs	Patent grant rate (%)	0.602	0.137	0.251	1.082
	Technology market turnover (ten thousand yuan)	6.797e+06	1.161e+07	5666	7.948e+07
	Contribution of cultural industries to economic growth (%)	0.078	0.082	0.004	0.442
Non-expected output	Ratio of per capita recreational consumption expenditure of urban and rural residents (%)	3.929	1.534	1.137	9.934



## 2.Spatio-temporal Characteristics of China’s Digital Cultural Industry Development Efficiency

### 2.1 Temporal Characteristics of China’s Digital Cultural Industry Development Efficiency

#### 2.1.1 Temporal Characteristics of the Development Efficiency of the Digital Cultural Industry at the Provincial Level

From the overall evaluation of the entire period, the average level of digital cultural industry development efficiency in China’s provincial regions was relatively low at 0.35, with significant disparities (Table 2). In terms of rankings, 11 provinces had digital cultural industry development efficiency above the average for the entire period, including 5 provinces from the eastern region, 3 from the central region, and 3 from the western region. In terms of provincial disparities, Beijing had the highest digital cultural industry development efficiency, with an average of 1.00, followed by Qinghai and Tianjin, with averages of 0.92 and 0.72, respectively. Yunnan, Henan, and Inner Mongolia ranked relatively lower. In terms of growth rates, provinces with higher digital cultural industry development efficiency during the entire period did not necessarily have faster annual growth rates. Beijing and Shanghai did not grow during the statistical period, while Gansu experienced negative growth. Among the 30 provinces, the annual growth rates of digital cultural industry development efficiency were relatively fast in most provinces. However, seven provinces—Hebei, Xinjiang, Ningxia, Guizhou, Guangxi, Shanxi, and Jiangsu—did not reach the average level for the entire period. Nevertheless, their annual growth rates of digital cultural industry development efficiency all achieved an average annual growth rate of over 29.13%, and through rapid growth, the digital cultural industry development efficiency of these provinces is expected to improve significantly. Additionally, the efficiency of digital cultural industry development in Gansu has declined, with an annual decrease of 0.92%. This is attributed to the lag in human and capital inputs compared to most other regions nationwide from 2011 to 2023, and the widening urban-rural gap at a rate of 4.87%, which exacerbated Gansu’s investment in human resources, capital, and other factors lagged behind most other regions in China, with the urban-rural gap growing at a rate of 4.87%. The combination of low-growth investment and unexpected outputs exacerbated the decline in the efficiency of digital cultural industry development. Therefore, the efficiency of Gansu’s digital cultural industry should be improved by prioritizing urban-rural integrated development and focusing on enhancing the efficiency of digital cultural industry development.

Table 2: Time-series characteristics of the efficiency of China’s provincial digital culture industry

Area/ provincial area sequence		Overall evaluation			Changes in characteristic periods			Changes in Characteristic Points			
		Entire period	Rank	Annual average growth rate	Growth period (2011-2015)	Adjustment period (2016-2020)	Quality improvement period (2021-2023)	2011	2016	2021	2023
Eastern region	Beijing	1.00	1	0.00	1.01	0.98	1.01	1.01	0.90	1.01	1.01
	Tianjin	0.72	3	0.14	0.87	0.52	0.78	0.37	0.48	1.03	0.47
	Hebei	0.18	22	1.22	0.08	0.04	0.57	0.12	0.05	1.02	0.14
	Shanghai	0.70	4	0.00	0.98	0.43	0.66	1.03	0.51	0.51	0.64
	Jiangsu	0.34	12	0.33	0.38	0.11	0.65	1.01	0.12	1.00	0.25
	Zhejiang	0.44	8	0.18	0.48	0.17	0.85	1.00	0.11	1.01	0.52
	Fujian	0.25	17	0.17	0.30	0.16	0.90	0.18	0.08	1.00	0.17
	Shandong	0.21	19	0.14	0.19	0.10	0.43	0.25	0.12	0.35	0.28
	Guangdong	0.27	15	0.22	0.20	0.15	0.60	0.20	0.10	1.00	0.34
	Hainan	0.66	5	0.64	0.79	0.31	1.01	1.00	0.09	1.01	1.01
	Average value	0.48	-	0.30	0.53	0.30	0.75	0.62	0.26	0.89	0.48

Area/ provincial area sequence		Overall evaluation			Changes in characteristic periods			Changes in Characteristic Points			
		Entire period	Rank	Annual average growth rate	Growth period (2011-2015)	Adjustment period (2016-2020)	Quality improvement period (2021-2023)	2011	2016	2021	2023
Central region	Shanxi	0.13	26	0.33	0.20	0.05	0.17	0.37	0.05	0.32	0.08
	Anhui	0.38	10	0.21	0.30	0.16	0.90	0.38	0.18	0.67	1.00
	Jiangxi	0.36	11	0.09	0.31	0.20	0.71	0.55	0.18	1.02	0.28
	Henan	0.10	29	0.19	0.09	0.05	0.22	0.12	0.06	0.31	0.11
	Hubei	0.39	9	0.14	0.26	0.25	0.84	0.26	0.19	0.91	0.61
	Hunan	0.26	16	0.22	0.21	0.15	0.53	0.16	0.15	0.31	0.33
	Average value	0.27	-	0.20	0.23	0.14	0.56	0.31	0.13	0.59	0.40
Western region	Neimenggu	0.11	28	0.04	0.18	0.04	0.12	0.36	0.03	0.13	0.13
	Guangxi	0.15	25	0.63	0.02	0.05	0.52	0.03	0.04	0.47	0.24
	Chongqing	0.19	20	0.23	0.27	0.11	0.20	0.35	0.20	0.24	0.15
	Sichuan	0.18	21	0.14	0.14	0.12	0.37	0.20	0.09	0.49	0.18
	Guizhou	0.15	24	0.76	0.10	0.06	0.41	0.12	0.04	1.00	0.11
	Yunnan	0.07	30	0.18	0.11	0.03	0.07	0.11	0.04	0.12	0.04
	Shanxi	0.28	14	0.10	0.20	0.21	0.55	0.21	0.17	0.50	0.46
	Gansu	0.61	6	-0.01	0.73	0.39	0.75	1.02	0.29	1.02	0.17
	Qinghai	0.92	2	0.08	1.00	0.78	1.02	1.04	1.03	1.03	1.00
	Ningxia	0.47	7	0.88	0.79	0.16	0.44	1.00	0.19	1.00	0.19
	Xinjiang	0.13	27	1.15	0.06	0.04	0.38	0.21	0.02	1.01	0.04
	Average value	0.30	-	0.38	0.33	0.18	0.44	0.42	0.20	0.64	0.25
Northeast region	Liaoning	0.17	23	0.20	0.21	0.07	0.26	0.51	0.05	0.45	0.13
	Jilin	0.25	18	0.01	0.41	0.11	0.20	0.75	0.08	0.26	0.17
	Heilongjiang	0.32	13	0.11	0.46	0.12	0.53	1.01	0.15	0.59	0.46
	Average value	0.24	-	0.11	0.36	0.10	0.33	0.75	0.09	0.44	0.25
Full period average		0.35	-	0.29	0.37	0.20	0.54	0.50	0.19	0.69	0.36

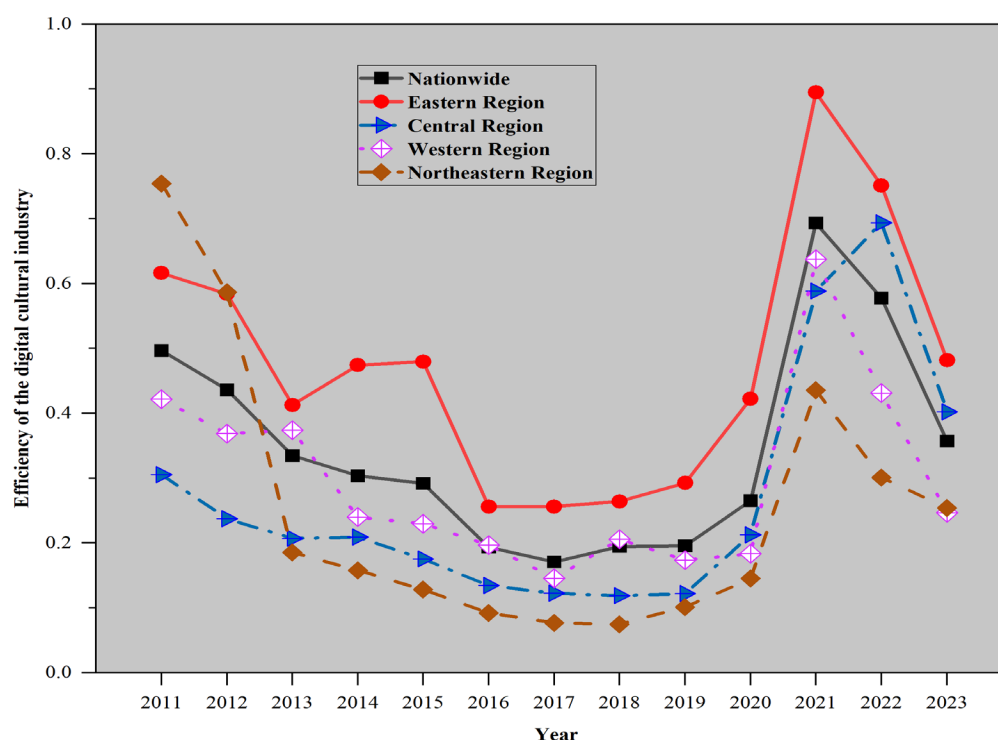
From the perspective of changes in characteristic periods and time points, the development efficiency of China's provincial digital cultural industries is significantly influenced by industrial policies and business layouts, exhibiting distinct stage-specific characteristics. From the perspective of three characteristic periods, China's provincial-level digital cultural industries exhibit a typical "V"-shaped pattern. Specifically, during the "growth period," the average efficiency of digital cultural industry development in 11 provinces exceeded the average level of that period; during the "adjustment period," this number decreased to 9 provinces; and during the "quality improvement period," it increased to 14 provinces. Among these, Beijing, Qinghai, Shanghai, Tianjin, Hainan, and Gansu performed well throughout the statistical period, consistently exceeding the average for each characteristic period. Looking at individual periods, during the "growth period," the average efficiency of digital cultural industry development in 26 provinces was lower than that of the initial year, with an overall downward trend during this period. Affected by the contradiction between high input and low output returns in industrial development and the decline in the growth rate of added value in major industries such as cultural manufacturing, the average efficiency of China's digital cultural industry development decreased by 41.18% in 2015 compared to 2011. During the "growth period," the efficiency of digital cultural industry development in the majority of provinces improved rapidly. Compared with 2016, the efficiency of digital cultural industry development in 24 provinces improved significantly in 2020, with an average

increase of 36.93%. In 2021, China's provincial-level digital cultural industry entered a period of quality improvement and efficiency enhancement, with 14 provinces exhibiting super-efficient development, exceeding the number of provinces with such performance at other time points. In 2022, the state issued the "Opinions on Promoting the Implementation of the National Cultural Digitization Strategy," which brought opportunities for the high-quality development of the digital cultural industry. Provinces across the country seized the window of opportunity for the development of the digital cultural industry, showcasing distinctive highlights in policy guidance, institutional safeguards, technological application, business model innovation, and scenario empowerment.

### 2.1.2 Temporal Characteristics of the Development Efficiency of the Digital Cultural Industry in Regions

The development efficiency of the digital cultural industry in China's four major regions exhibits a fluctuating pattern of decline and rise, with an overall trend of continuous weakening (Figure 2). The eastern region has consistently remained above the national average, while the central, western, and northeastern regions have generally lagged behind the national average. During the "growth period," the annual growth rates of the digital cultural industry development efficiency in the eastern, central, western, and northeastern regions were 30.45%, 19.73%, 38.06%, and 10.83%, respectively. This indicates that during the adjustment phase of the digital cultural industry, the development efficiency of the digital cultural industry in all four regions declined to varying degrees, with the northeastern region experiencing the most significant decline, dropping by 82.99% compared to 2011. During the "adjustment period," except for the western region, which remained basically stable, the development efficiency of the digital cultural industry in the other regions increased, with the eastern region seeing the fastest growth, rising by 64.88% in 2020 compared to 2016. During the "quality improvement period," the development efficiency of the digital cultural industry in the four major regions reached its peak in 2021, thanks to the support of the "Opinions on Promoting the High-Quality Development of the Digital Cultural Industry," which boosted confidence in the development of the digital cultural industry. However, subsequently, due to structural imbalances in the allocation of resources and elements in the digital cultural industry, as well as difficulties in deepening and extending the industrial chain, value chain, innovation chain, and talent chain, the development of the digital cultural industry in the four major regions slowed down and even showed a noticeable downward trend. Nevertheless, it should be noted that during this phase, the average development efficiency of the digital cultural industry in the eastern and central regions remained higher than the national average.

Figure 2 Trends in the efficiency of digital cultural industry development in China's four major regions



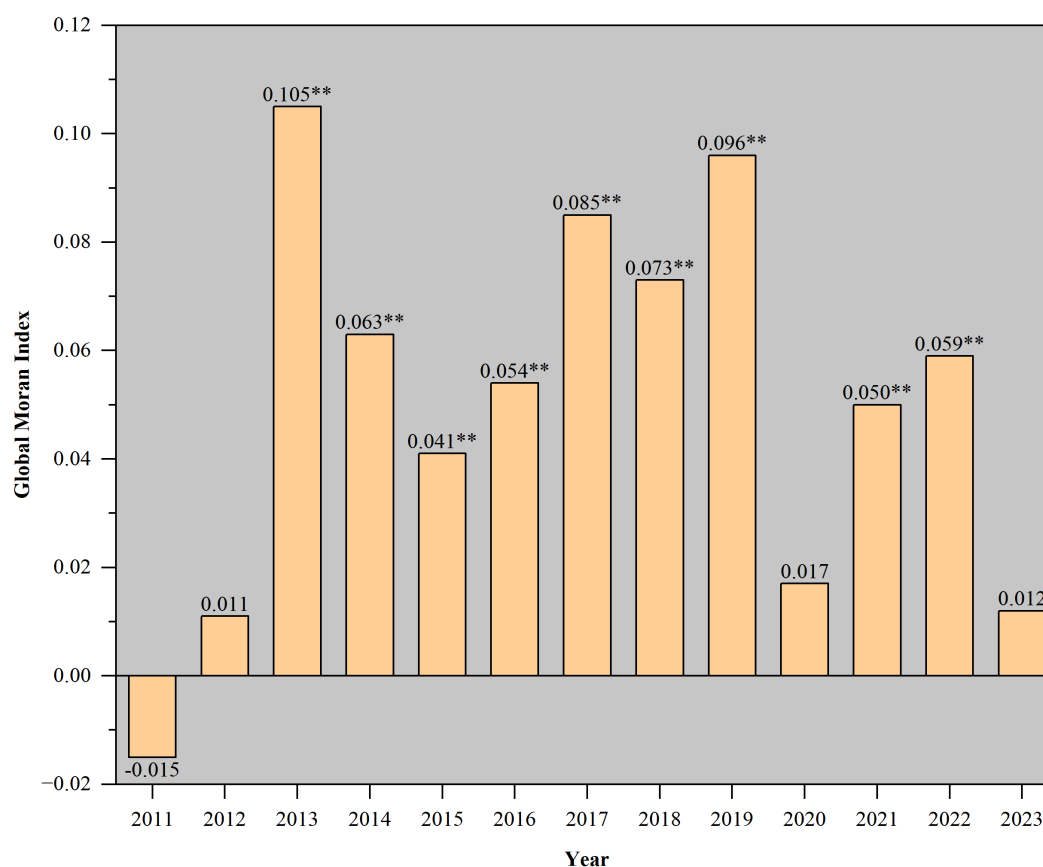
## 2.2 Spatial characteristics of the development efficiency of China's digital culture industry

### 2.2.1 Global spatial agglomeration characteristics of the development efficiency of the digital culture industry

From 2011 to 2023, the overall Moran's index exhibited a fluctuating downward trend, indicating that the spatial clustering efficiency of China's digital cultural industry is gradually weakening (Figure 3). Specifically, the global Moran Index was -0.015 in 2011, with a P-value of 0.290, which is much larger than 0.05. In 2012, although the global Moran Index turned from negative to positive to 0.011, the P-value was 0.101, which is still larger than 0.05, indicating that the development efficiency of China's digital culture industry lacked significant spatial agglomeration characteristics on the global scale from 2011 to 2012. The reason for this is that over the past two years, China's digital culture industry has been in a budding and growing phase, with low allocation efficiency of policies, technologies, and resources. The spatial layout of the industry was not yet clear, and the industry had not yet formed stable spatial correlations. In the following years, the global Moran index is positive, in which the P-value is less than 0.05 from 2013 to 2019 and in 2021 and 2022, indicating that there is a significant spatial agglomeration characteristic in the development efficiency of China's digital culture industry in these nine years, but the P-value in 2020 and 2023 is greater than 0.05, indicating that China's digital culture industry in these two years does not present a significant overall Clustering characteristics. In terms of period, the global Moran index in the "growth period", "adjustment period" and "quality improvement period" shows a "Λ" distribution. The global Moran Index in the "growth period", "adjustment period" and "quality improvement period" is distributed in a "Λ" shape, which shows the trend of "increasing and then decreasing", indicating that there are obvious differences in the spatial agglomeration characteristics of the development efficiency of the digital culture industry in each period.

Note: \*\* indicates significance at a 5% significance level.

Fig. 3 Global spatial agglomeration of the development efficiency of China's digital culture industry



### 2.2.2 Local spatial agglomeration characteristics of the development efficiency of the digital culture industry

The spatial distribution of the development efficiency of China's digital culture industry is mainly characterized by "H-H" and "L-L" agglomeration (Table 3). Among them, "high - high" agglomeration is mainly distributed in Beijing, Tianjin,

Shanxi, Shandong, Qinghai, Ningxia, Gansu and other provinces, while “low - low” agglomeration is mainly distributed in Zhejiang, Anhui, Jiangxi, Hubei, Hunan, Guangxi, Hainan, Chongqing, Sichuan, Guizhou, Yunnan and other provinces. It is worth noting that the development efficiency of the digital culture industry in some provinces is characterized by “high-low” agglomeration, such as Guangdong, Fujian, and Jiangsu. In terms of period, the local spatial agglomeration characteristics of the development efficiency of China’s digital culture industry in the “growth period”, “adjustment period” and “quality improvement period” are quite different. In the “growth period”, the “high-high” agglomeration and “low-low” agglomeration have a “Λ” distribution, and the “adjustment period” has a “Λ” distribution, and the “adjustment period” has a “Λ” distribution. The “adjustment period” is stable, and the “quality improvement period” has a downward trend, reflecting that the local spatial distribution of the development efficiency of China’s digital culture industry is unbalanced.

*Table 3: Local spatial clustering of efficiency in China’s digital culture industry*

Year	High-High agglomeration	Low-High agglomeration	Low-Low agglomeration	High-Low agglomeration
2011	Neimenggu, Gansu, Qinghai, Ningxia (4)	Tianjin, Hebei, Jilin, Shanghai, Anhui, Jiangxi, Shandong, Henan, Hainan, Shanxi, Xinjiang, Heilongjiang (12)	Zhejiang, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan (6)	Beijing, Shanxi, Liaoning, Jiangsu, Fujian, Hubei, Hunan, Guangdong (8)
2015	Beijing, Tianjin, Gansu, Ningxia (4)	Hebei, Neimenggu, Liaoning, Shanghai, Zhejiang, Anhui, Shandong, Henan, Shanxi, Xinjiang (10)	Jilin, Heilongjiang, Fujian, Jiangxi, Hubei, Hunan, Guangdong, Guangxi, Hainan, Chongqing, Sichuan, Guizhou, Yunnan (13)	Shanxi, Jiangsu, Qinghai (3)
2019	Beijing, Tianjin, Shanxi, Shandong, Shanxi, Gansu, Qinghai (7)	Hebei, Neimenggu, Liaoning, Jilin, Heilongjiang, Henan, Ningxia, Xinjiang (8)	Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Hubei, Hunan, Guangdong, Guangxi, Hainan, Chongqing, Sichuan, Guizhou, Yunnan (15)	-
2023	Beijing, Tianjin, Shanxi, Liaoning, Jiangsu, Anhui, Shandong (7)	Hebei, Neimenggu, Jilin, Shanghai, Zhejiang, Jiangxi, Henan, Hubei, Gansu, Ningxia, Xinjiang (11)	Heilongjiang, Fujian, Hunan, Guangxi, Hainan, Chongqing, Sichuan, Guizhou, Yunnan (9)	Guangdong, Shanxi, Qinghai (3)

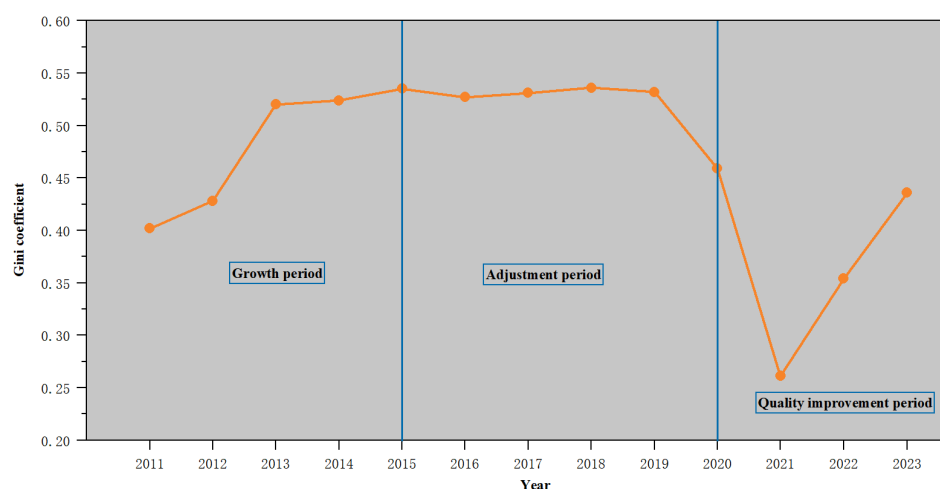
### 3. Spatial Differences in the Development Efficiency of China’s Digital Culture Industry

#### 3.1 Regional differences in the development efficiency of the digital culture industry

According to Figure 4, the overall Gini coefficient of the development efficiency of China’s digital culture industry fluctuates between 0.26 and 0.54, with the overall state decreasing and then increasing, indicating that the regional gap in the development efficiency of the digital culture industry narrows more slowly. During the statistical period, the Gini coefficient of the development efficiency of China’s digital culture industry increased by an average of 2.69% per year, and compared with 2011, it increased by 8.46% in 2023.

Sub-period, “growth period”, China’s digital culture industry development efficiency of the regional gap is expanding trend, the average growth rate of 7.71%, the economic strength of the regions and industrial resource endowment there is a significant gap, the eastern region shows a strong first-mover advantage. In the “adjustment period”, the regional gap did not continue the expansion trend of the previous period, with an average growth rate of 2.85%, down 4.86 percentage points, the gap between the regions is shrinking, thanks to the period of the various regions continue to strengthen the digital culture industry resource factor flow and optimize the allocation efficiency, the formation of cross-regional growth poles. During the “quality improvement period”, the average growth rate was 5.22%, 2.37 percentage points higher than that of the “adjustment period” and 2.49 percentage points lower than that of the “growth period”. During this period, all regions accelerated the promotion of high-quality development of the digital culture industry, and innovation resources, high-end talents, and data elements accelerated their concentration in megacities, leading to a widening of the gap between regions.

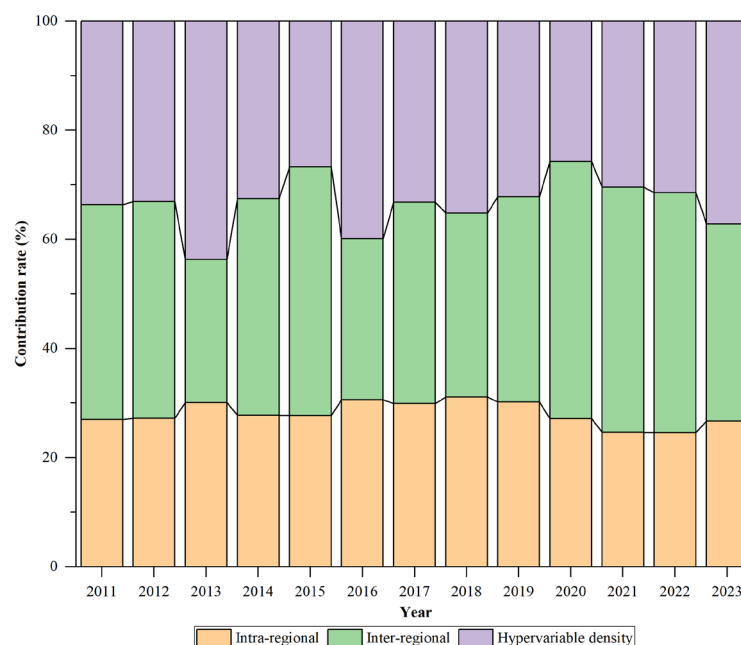
Fig. 4 Overall regional gaps in the development efficiency of the digital culture industry in the four major regions of China



### 3.2 Sources of the spatial gap in the development efficiency of the digital culture industry

From the perspective of the spatial sources of regional disparity, it mainly includes inter-regional disparity, intra-regional disparity, and hypervariable density. As can be seen from Figure 5, the contribution rate of intra-regional disparity is from 24.57% to 31.10%, the contribution rate of inter-regional disparity is from 26.25% to 47.10%, and the contribution rate of hyper-variable density is from 25.76% to 43.69%, indicating that the inter-regional disparity is the dominant factor of the spatial disparity of China's development efficiency of the digital culture industry and that reducing the disparity between different regions is the response to the problem of uneven development of the digital culture industry. Key. In addition, the contribution rate of hypervariable density follows closely, indicating that the phenomenon of cross-overlap in different regions also has a greater impact on the regional gap in the development efficiency of China's digital culture industry, and provinces under the same level of efficiency are very likely to belong to different tiers in different regions, which increases the degree of regional differences in the development efficiency of the digital culture industry. From the perspective of the three major periods, the contribution rate of intra-regional differences shows an inverted "V" type change, and the contribution rate of inter-regional and hyper-variable density shows a "V" type change, from the "growth period" to the "quality improvement period", from the "growth period" to the "quality improvement period". From the "growth period" to the "quality improvement period", the average contribution rate of inter-regional differences is 38.14%, 36.97%, and 41.66% respectively, indicating that it is still the most important source of regional disparities in the period, which is consistent with the results of the whole period.

Fig. 5 Spatial sources of regional disparities in the development efficiency of China's digital culture industry





### 3.3 Decomposition of the Gini coefficient of development efficiency of the digital culture industry

On the one hand, the Gini coefficient of the development efficiency of the digital culture industry among China's four major regions during the statistical period generally shows a fluctuating downward trend. The decline is especially obvious in the period from 2019 to 2021. Specifically, the inter-regional Gini coefficients of the eastern region - western region and the eastern region - northeastern region are larger, and the average value is greater than 0.50, and the inter-regional Gini coefficient of the northeastern region - central region is smaller, and the average value is 0.36. It can be seen that there is a clear gap between the regions with higher efficiency in the development of the digital culture industry and those with lower efficiency, and in contrast to this, the regions with lower efficiency in the development of the digital culture industry The difference between them is not big, but overall the regional gap in the development efficiency of the digital culture industry in different regions still has different degrees of change.

On the other hand, the results of the Gini coefficient decomposition of the development efficiency of the digital culture industry within the four major regions of China are shown in Table 4, and there is a significant difference between the Gini coefficients within each region, among which the Gini coefficient within the western region is the largest, followed by the eastern and central regions, and the northeastern region is the smallest. From the previous analysis, it can be seen that the development efficiency of the digital culture industry in the Western region is lower, the intra-regional differences are larger, and the uneven development is particularly significant. In contrast, the eastern region's digital culture industry development efficiency is relatively high, and its internal development is generally more balanced. From the perspective of the time change, the Gini coefficient of the four regions generally shows a fluctuating upward trend, indicating that the differences in the development efficiency of its internal digital culture industry are gradually increasing.

Table 4: Dagum gini coefficient difference decomposition results

Year	Intra-regional Gini coefficient				Inter-regional Gini coefficient					
	Eastern region	Central region	Western region	Northeastern region	East & Central	East& West	East & Northeast	Central & Northeast	Central& Western	West & North-east
2011	0.34	0.27	0.46	0.15	0.46	0.43	0.29	0.43	0.44	0.41
2012	0.35	0.20	0.49	0.25	0.50	0.46	0.34	0.42	0.45	0.43
2013	0.47	0.22	0.57	0.37	0.50	0.53	0.55	0.35	0.57	0.60
2014	0.45	0.24	0.55	0.39	0.54	0.58	0.62	0.36	0.49	0.54
2015	0.45	0.22	0.56	0.37	0.58	0.59	0.66	0.35	0.47	0.54
2016	0.50	0.23	0.59	0.25	0.50	0.58	0.55	0.31	0.49	0.55
2017	0.51	0.23	0.58	0.14	0.51	0.60	0.57	0.31	0.49	0.53
2018	0.51	0.26	0.59	0.10	0.51	0.57	0.59	0.32	0.52	0.59
2019	0.49	0.31	0.59	0.10	0.53	0.58	0.53	0.28	0.53	0.52
2020	0.40	0.37	0.45	0.13	0.47	0.53	0.54	0.36	0.43	0.37
2021	0.11	0.27	0.31	0.17	0.27	0.25	0.37	0.29	0.32	0.35
2022	0.17	0.28	0.48	0.28	0.24	0.40	0.44	0.49	0.43	0.47
2023	0.34	0.43	0.47	0.28	0.40	0.49	0.42	0.44	0.50	0.41

## 4. Research Conclusions and Policy Recommendations

This paper constructs a global super-efficiency EBM model that takes into account non-expected outputs, scientifically and systematically measures the development efficiency of the digital cultural industry in 30 provinces of China from 2011 to 2023, and further reveals its temporal and spatial characteristics and the degree of spatial differentiation, drawing the

following conclusions:

(1) During the statistical period, the overall efficiency of China's digital cultural industry development was relatively low, with an average efficiency of 0.35. The efficiency of digital cultural industry development exhibited distinct temporal and regional characteristics. From the perspective of three characteristic periods, China's provincial-level digital cultural industries exhibited a typical "V"-shaped pattern, with average efficiency levels during the "quality improvement period" and "growth period" generally higher than those during the "adjustment period." Additionally, the efficiency of digital cultural industry development in eastern regions was significantly higher than that in other regions.

(2) In terms of spatial agglomeration characteristics, the global Moran index of China's digital cultural industry development efficiency showed an overall fluctuating downward trend, with the global Moran index of the three characteristic periods exhibiting a "Λ" distribution pattern, all indicating a fluctuating decline. The local Moran index revealed that the spatial distribution of China's digital cultural industry development efficiency primarily featured "high-high" and "low-low" agglomeration patterns, with significant differences in local spatial agglomeration characteristics across the three characteristic periods.

(3) In terms of the sources of spatial disparities, the overall disparity in the efficiency of China's digital cultural industry development shows a fluctuating upward trend, with inter-regional disparities being the dominant factor in spatial disparities in the efficiency of China's digital cultural industry development, with a contribution rate ranging from 26.25% to 47.10%. Based on the results of the Gini coefficient decomposition, during the statistical period, the Gini coefficient of digital cultural industry development efficiency among China's four major regions showed an overall fluctuating downward trend, with the internal imbalance of digital cultural industry development efficiency in the western region becoming more pronounced.

Based on the above conclusions, the following recommendations are proposed:

(1) Strengthen the application of technological innovation to promote the quality and efficiency of the digital cultural industry<sup>[19]</sup>. Under the national strategy of cultural digitization, new technologies such as digital technology, cloud computing, big data, and artificial intelligence are upgrading from cultural dissemination tools to industrial innovation engines. This requires the accelerated establishment of a tracking and monitoring system for the development efficiency of the digital cultural industry to achieve precise alignment between policy tools and industrial cycles. In addition, it is necessary to significantly improve the pure technical efficiency of the digital cultural industry, enhance the efficiency of input and output utilization, break through the barriers of management inefficiency<sup>[20]</sup>, expand the talent chain, innovation chain, and value chain of the digital cultural industry, and maximize the source function of the digital cultural industry to promote the upgrading of the digital cultural industry.

(2) Leverage regional comparative advantages and formulate digital cultural industry development strategies and measures based on local conditions<sup>[21]</sup>. The regional disparities in the development efficiency of China's digital cultural industry are widening. When formulating digital cultural industry development strategies and measures, all regions must focus on highlighting their industrial characteristics and leveraging their comparative advantages, accurately positioning themselves within the broader context of the high-quality development of the national cultural industry, and meeting demand, while strengthening planning coordination<sup>[22]</sup>. Eastern regions should regard the layout of the digital cultural industry as an important lever for accelerating the construction of a modern industrial system, strengthening the coordination and integration of the digital cultural industry with the digital economy, and providing a model for the development of the digital cultural industry in other regions<sup>[23]</sup>. Central regions should strengthen the overall planning of the digital cultural industry, focus on the forward-looking layout of digital cultural industry formats, and enhance the conversion and application of digital cultural value in various economic sectors. Western regions should rely on industry-leading platforms such as the Western Digital Publishing Alliance, the Western Digital Publishing Annual Conference, China Western Cultural Industry Expo, and other high-end industry platforms to gain a deep understanding of the bottlenecks and obstacles constraining the development of the digital cultural industry and explore development policies for improving the quality and efficiency of the digital cultural industry. The northeastern region should increase research and development of digital infrastructure equipment and application technologies, take multiple measures to build a digital content production belt, industrial heritage digital



revitalization demonstration zone, and cross-border digital cultural trade corridor, and gradually narrow the spatial gap between regions in the digital cultural industry.

(3) Break through regional barriers in the digital cultural industry and resolve barriers to regional agglomeration. It is necessary to accelerate the pilot program for the registration and trading of digital cultural data elements, break down existing regional barriers and restrictions on the flow of elements, and promote the value of data assets in different regions to empower the development of the digital cultural industry<sup>[24]</sup>. We should also take the layout of digital cultural industry business models as a starting point to strengthen the coordinated improvement of regional digital cultural industry development efficiency<sup>[25]</sup>. In addition, we should establish a compensation mechanism for positive externalities in the digital cultural industry space at the appropriate time, formulate technical spillover assessment and incentive plans for “high-high” agglomeration zones, and accelerate the formation of a good ecological pattern of spatial linkage in the digital cultural industry.

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## Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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# Research on the Knowledge Exchange Efficiency of Academic Journals in the Field of Journalism and Publishing Based on the Three-Stage DEA Model

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**Abstract:** This study systematically evaluates the operational efficiency of academic journals in the field of journalism and publishing in China based on the three-stage DEA model, and finds that the efficiency of journals shows significant differentiation characteristics. The research shows that four journals, including Acta Editologica, continuously maintain DEA effectiveness, demonstrating excellent management efficiency. Twelve journals, such as Editors' Friend, have improved their comprehensive efficiency after excluding environmental factors, indicating that their management potential is restricted by external conditions. Four journals, including Editorial Research, have decreased their comprehensive efficiency after excluding environmental factors, indicating that external conditions can promote their management potential. Further analysis reveals that the number of geographical distributions, the citation half-life, and the years of publication are the key environmental factors affecting efficiency. Based on this, the study proposes differentiated improvement strategies: highly efficient journals should deepen digital transformation and establish an intelligent manuscript review system; environmentally sensitive journals need to optimize regional resource allocation and establish a collaborative editing center; and low-efficiency journals should achieve structural reforms through process reengineering and content innovation.

**Keywords:** Journalism and Publishing; Academic Journals; Knowledge Exchange Efficiency; Three-stage DEA Model

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## 1.Introduction and Literature Review

As a vital medium for disseminating scholarly information, journals facilitate knowledge exchange and sharing through cross-referencing, reflecting the flow and evolution of knowledge <sup>[1]</sup>. Exploring the developmental patterns of academic journals holds significant practical value for promoting their rational utilization and advancing disciplinary development.

<sup>[2]</sup> In recent years, regarding the strategic planning and top-level design of academic journals, the Publicity Department of the CPC Central Committee, the Ministry of Education, and the Ministry of Science and Technology jointly issued the "Opinions on Promoting the Prosperity and Development of Academic Journals." This document further clarifies the path for journal prosperity and development, offering new perspectives for academic journal advancement. As a vital component of information and ideological exchange, the news and publishing industry forms the foundation for enhancing our nation's cultural soft power. <sup>[3]</sup> As a vital platform for enhancing the discourse power of the news and publishing industry, academic

journals in this field shoulder the critical responsibilities of facilitating academic exchange and guiding scholarly trends. They play an irreplaceable role in the prosperity and development of the news and publishing sector. Evaluating the knowledge efficiency of these academic journals from an input-output perspective offers significant insights for assessing their position and function within the knowledge dissemination process.

The efficient dissemination of academic journals helps break down knowledge barriers and promotes cross-disciplinary integration. Current quantitative studies comparing knowledge exchange efficiency across different journal types from an input-output perspective include: <sup>[4]</sup> Cheng Huiping et al. employed the DEA-CCR model to evaluate citation efficiency among 18 journals under fixed returns. Findings indicated that library science journals exhibited the highest citation efficiency, while information science journals ranked lowest, with the gap between journals narrowing. <sup>[5]</sup> Li Lin et al. assessed the input-output performance of 17 Chinese core science and technology journals using non-cooperative game theory and DEA/hedge domain games. The findings revealed that some high-impact journals yielded less-than-satisfactory evaluation results due to their high publication volume. Changes in weighting biases could lead to three outcomes: increased, unchanged, or decreased evaluation values. Meanwhile, journal self-citation frequency exhibited three patterns: excessive, moderate, and insufficient. <sup>[6]</sup> Wang Hui et al. employed the SBM model and nonparametric kernel density estimation to investigate knowledge exchange efficiency in Chinese science and technology journals. Findings indicate that while library and information science journals exhibit high overall knowledge exchange efficiency, they show a tendency toward polarization. <sup>[7]</sup> Wang Yiwen analyzed evolutionary trends by introducing kernel density estimation and Markov chains to the global super-efficiency SBM model for measuring knowledge exchange efficiency, thereby capturing efficiency from a static perspective. Using dynamic QCA methods, they investigated the changes in configuration effects influenced by factors over time and individual effects. The findings revealed significant disparities in knowledge exchange efficiency among Chinese journals in the field of information resource management, exhibiting typical imbalances. Knowledge exchange efficiency levels demonstrated a “Matthew effect,” with factors influencing knowledge efficiency showing pronounced time effects and individual effects. <sup>[8]</sup> Jia Xunliang et al. employed a super-efficiency DEA-Malmquist model to analyze citation efficiency across 30 sports academic journals. Findings indicate that sports academic journals exhibit overall high knowledge exchange efficiency (0.975), with annual trends following a “V”-shaped pattern, reaching lowest efficiency values in 2015–2016. <sup>[9]</sup> Tan Chunhui et al. investigated the knowledge exchange efficiency of Chinese humanities and social sciences journals, concluding that the overall level of these journals is relatively low with significant disparities. Interdisciplinary differences constitute the primary source of variation. While efficiency levels are gradually increasing, absolute gaps continue to widen, indicating polarization. <sup>[10]</sup> Li Xiacong et al. employed DEA-SBM and SuperSBM models to assess the knowledge exchange efficiency of 11 core journals operated by publishing enterprises, proposing improvement measures. The study indicates that these journals possess acceptable knowledge exchange and dissemination capabilities, yet there remains 11.4% room for improvement, with Publishing Panorama demonstrating the highest potential. Conversely, “ineffective” journals commonly exhibit issues such as redundant literature input, low impact factors, and low total citation frequencies.

Some scholars have also measured the knowledge efficiency of journals and analyzed the factors influencing their efficiency. For instance, <sup>[11]</sup> Zhang Lei focused on examining the impact of five variables—journal scale, dissemination time, distribution channels, regional diffusion capacity, and journal internationalization—on knowledge exchange efficiency. <sup>[12]</sup> Wang Shuqiao et al. drawing on Zhang Lei’s research experience, selected five factors: internationalization level, publication duration, regional dissemination capability, regional economic development level, and journal academic paper quality. <sup>[13]</sup> Li Ping et al. selected five factors: internationalization level, publication duration, regional dissemination capability, regional economic development level, and journal academic paper quality. <sup>[13]</sup> Li et al. emphasized that internationalization level is a crucial factor influencing agricultural economics journals, with “funding-to-paper ratio” and “publication duration” having positive effects, while other factors had limited impact, and institutional breadth did not enhance efficiency. <sup>[14]</sup> McWilliams examined the effects of editorial board size, subscription fees, selection ratios, and special issue papers on academic exchange outcomes. While all these scholars employed DEA methods to measure journal knowledge exchange efficiency, they utilized different approaches for factor analysis. Most adopted the Tobit model for efficiency factor analysis. <sup>[15]</sup> Wan Li employed

both Super-SBM and Tobit models, revealing that citation half-life, number of institutional affiliations, and publication frequency exerted significant positive effects on efficiency, while publication duration showed no significant positive impact. However, in <sup>[16]</sup> Qiu Junping et al., while studying the knowledge exchange efficiency of comprehensive humanities and social sciences journals, found that journal academic quality, publication frequency, and journal age are all important factors, whereas journal aging rate and online dissemination status had no significant impact. Evidently, different journal types face distinct influencing factors, and the same factor exerts vastly different effects across types. This provides a crucial reference for subsequent research on factors affecting knowledge exchange efficiency in news and publishing journals.

In summary, while existing research on journal knowledge exchange efficiency is relatively extensive, it lacks a temporal perspective and fails to accurately capture the phased characteristics of such efficiency. To enrich current scholarship, this paper builds upon prior studies by examining the influence of environmental factors across time spans, thereby conducting a more in-depth investigation into the knowledge efficiency of academic journals in journalism and publishing.

## 2. Model Construction, Indicator Selection, and Data Sources

### 2.1 Model Construction

#### 2.1.1 First-Stage BCC Model

The first stage employs a traditional BCC model, featuring a non-Archimedean infinitesimal DEA model as shown in Equation (1).

$$\begin{cases} \min[\theta - \varepsilon(\hat{e}^T s^- + e^T s^+)] \\ \sum_{g=1}^n X_g \lambda_g + s^- = \theta X_{g0} \\ \sum_{g=1}^n Y_g \lambda_g - s^+ = Y_{g0} \\ \sum_{g=1}^n \lambda_g = 1 \\ \lambda_g \geq 0, g = 1, 2, \dots, n; s^+ \geq 0, s^- \geq 0 \end{cases} \quad (1)$$

In the equation:  $[X_g = (X_{1g}, X_{2g}, \dots, X_{mg})]^T$  represents the input variables of the decision-making unit;  $[Y_g = (Y_{1g}, Y_{2g}, \dots, Y_{sg})]^T$  are the output variables of the decision unit;  $X_{g0}$  and  $Y_{g0}$  are the input and output variables of the  $g_0$ th decision unit;  $s^+$  and  $s^-$  are the output and input slack variables;  $n$  denotes the number of decision units;  $\lambda_g$  represents the decision variables;  $[e = (1, \dots, 1)]^T \in E_m$ ;  $[\hat{e} = (1, \dots, 1)]^T \in E_s$ ;  $\varepsilon$  is a non-Archimedean infinitesimal;  $\theta$  is the comprehensive efficiency value of the decision unit, used to evaluate effectiveness by comparison with 1.

#### 2.1.2 Second-Stage SFA Model

Establish a theoretical model for slack variables and environmental explanatory variables:

Establish a theoretical model for slack variables and environmental explanatory variables:

$$\begin{cases} s_{ig} = f(z_g, \beta^i) + v_{ig} + u_{ig} \\ i = 1, 2, \dots, n; g = 1, 2, \dots, m \end{cases} \quad (2)$$

In the equation,  $Z_g = (Z_{1g}, Z_{2g}, \dots, Z_{Pg})$  represents  $P$  environmental variables, and  $\beta^i$  denotes the vector of parameters to be estimated for the environmental variables.  $f(z_g, \beta^i) = z_j \beta^i$  represents the influence of environmental variables on the slack variable  $s_{ig}$ .  $v_{ig} + u_{ig}$  constitutes the mixed error term, where  $v_{ig}$  is the random error term assumed to follow a normal distribution, i.e.,  $v_{ig} \sim N(0, [\sigma^2]_{ui})$ ,  $u_{ig}$  represents managerial inefficiency, assumed to follow a truncated normal distribution, i.e.,  $u_{ig} \sim N^+(u^i, \sigma^2_{ui})$ , and  $v_{ig}$  and  $u_{ig}$  are assumed to be independent and uncorrelated. Specifically, let  $\gamma = \sigma^2_{ui} / (\sigma^2_{ui} + \sigma^2_{vi})$  for comparison with 1. Then, by conditionally estimating  $\hat{E}[u_{ig} | v_{ig} + u_{ig}]$  of managerial inefficiency, the estimate of the random error is obtained:

$$\begin{cases} E[v_{ig} | v_{ig} + u_{ig}] = s_{ig} - z_g \hat{\beta}^i - \hat{E}[u_{ig} | v_{ig} + u_{ig}] \\ i = 1, 2, \dots, n; g = 1, 2, \dots, m \end{cases}$$

Finally, this paper adjusts the investment levels for other journals based on the most efficient journal investment levels identified in the news and publishing sector:

$$\begin{cases} x_{ig}^* = x_{ig} + [\text{Max}_g\{z_g\hat{\beta}^n\} - z_g\hat{\beta}^n] + [\text{Max}_g\{\hat{v}_{ig}\} - \hat{v}_{ig}] \\ i = 1, 2, \dots, n; g = 1, 2, \dots, m \end{cases} \quad (4)$$

In the equation:  $x_{ig}^*$  and  $x_{ig}$  represent the adjusted and initial input values, respectively, while  $\hat{\beta}^m$  denotes the estimated value of the environmental variable parameter.  $[\text{Max}_g\{z_g\hat{\beta}^m\} - z_g\hat{\beta}^m]$  represents the constraint that all journals share the same environment, while  $[\text{Max}_g\{\hat{v}_{ig}\} - \hat{v}_{ig}]$  represents that each journal exists in the same natural state.

### 2.1.3 Third-Stage BCC Model

Using the adjusted input data obtained in the second stage, combined with the original output data, both are substituted into the BCC model for solution.

## 2.2 Indicator Selection and Data Sources

All research data in this paper are sourced from the “China Science and Technology Journal Citation Reports” covering 2013–2020. As a complex system involving multivariate inputs and outputs, news and publishing journals require in-depth analysis and evaluation of their input-output relationships within knowledge exchange processes. Studying these relationships essentially explores the interdependencies among journals in knowledge exchange activities. Following relevant literature practices, this study uses indicators from the China Science and Technology Journal Citation Report to represent the development level of the news and publishing industry.

For input indicators, this paper selected source document volume, average citation count, and proportion of funded papers as input metrics for the news and publishing industry. For output indicators, this study selected expanded total citation frequency, expanded impact factor, expanded number of citing journals, and expanded disciplinary impact indicators as output factors for news and publishing journals. Regarding environmental variables, this study considered the geographical distribution of news and publishing journals, article novelty, and journal publication duration, selecting regional publication count, citation half-life, and publication duration as environmental variable factors. Relevant indicator tables are shown in Table 1

Table 1: Indicator Selection Table

Indicator Category	Indicator Name	Definition	Unit
Input Indicators	Source Literature Volume	Total number of articles published in source journals during the statistical year, serving as the basis for citation data collection	Articles
	Average Citations per Article	Average number of references cited per article in source journals	Citations/Article
	Funded Article Ratio	Proportion of articles funded by various grants among all articles in source journals	%
Output Metrics	Expanded Total Citations	Total number of citations received by all articles published in the journal since its inception during the statistical year	Times/Journal
	Expanded Impact Factor	The frequency with which articles published in a journal are cited by other academic literature within a specific period	%
	Expanded Number of Citing Journals	Number of journals that cite the evaluated journal	Articles
	Expanded Disciplinary Impact Metric	Refers to the proportion of journals within the journal's discipline that cite it relative to the total number of journals in that discipline	%
Environment Variables	Regional Distribution Count	Refers to the number of regions covered by articles published in the source journal	Regions
	Citation Half-Life	Refers to the time period within which the latter half of all references cited by the journal were published	%
	Years in Publication	Refers to the number of years the journal has been continuously published since its founding	Years



### 3. Empirical Analysis

#### 3.1 Phase One Results Analysis

Using specialized software to measure the knowledge exchange efficiency of academic journals in the field of journalism and publishing, the following conclusions were drawn based on the data analysis. The mean comprehensive efficiency of each academic journal in the journalism and publishing field during the observation period shows that the journals *Acta Editologica*, *Modern Communication*, *Journalism & Communication*, and *News and Writing* all achieved a mean comprehensive efficiency of 1. Meanwhile, the journals *Editorial Journal*, *Contemporary Communication*, *TV Research*, *Journal of International Communication*, *Journalism University*, *Chinese Editors Journal*, *China Radio & TV Academic Journal*, and *Chinese Journal of Scientific and Technical Periodicals* all achieved comprehensive efficiency values above 0.9. The remaining journals all had comprehensive efficiency values below 0.9. The reason the average values approached 1 was due to occasional invalid efficiency values in the statistical years.

#### 3.2 Two-Stage Results Analysis

The difference between the optimal efficiency input and actual input measured by DEAP 2.1 was used as the slack variable. With the slack variable as the dependent variable, environmental calculations were performed on the data using Frontier 4.1. Due to the large volume of results, this study selected 2013, 2016, and 2019 as representative years to reflect the SFA results for the second stage across the 2012–2019 time span. The relevant results are shown in Table 3. The LR values for all input slack quantities passed the 5% significance test, indicating that the three selected environmental variables significantly influence the input variable slack quantities.

Table 2: Two-Stage Results Presentation Table

Variable Name Coefficient	Number of Source Publications			Average Citations			Funded Papers Ratio		
Year	2013	2016	2019	2013	2016	2019	2013	2016	2019
Coefficient	-0.075	0.046	-0.052	-0.018	0.054	-0.032	-0.126	-0.089	-0.162
Regional Distribution	0.010	-0.011	0.016	0.009	-0.009	0.015	0.081	0.008	0.367
Citation Half-Life	-0.023	-0.005	-0.014	-0.022	-0.022	0.019	-0.071	-0.072	0.235
Years in Publication	0.049	-0.022	0.016	0.011	-0.022	-0.012	0.034	0.077	-0.363
$\delta$	0.013	0.012	0.001	0.000	0.000	0.001	0.007	0.015	0.023
$\gamma$	1.000	1.000	0.950	0.950	0.950	0.950	0.951	0.987	0.987
LR Test Value	17.456***	18.398***	51.365***	7.852**	61.109***	8.671**	12.000**	13.786***	10.042**

Note: \* indicates  $p < 0.1$ , \*\* indicates  $p < 0.05$ , \*\*\* indicates  $p < 0.01$

After separating the data and analyzing overall changes, it was found that among the 20 selected DMUs, all inputs showed an increase from 2012 to 2019 after operational adjustments. The adjusted increases in source literature volume and average citation count were particularly noticeable, with change values ranging from 0 to 0.6, mostly between 0.1 and 0.4. Only a small portion showed increases below 0.1 or above 0.5. The fund-to-paper ratio exhibited minimal variation, with changes ranging between 0 and 0.1.

As shown in Table 2, during the 2012-2019 period, one-third of the coefficients for environmental variables at the regional distribution level were negative, while two-thirds were positive. The positive and negative values for source document volume, average citation count, and funded paper ratio showed no consistent annual pattern. This indicates that regional distribution numbers exert both beneficial and detrimental effects on these metrics, with detrimental impacts predominating. These effects also exhibit coupling with other environmental factors.

Regarding citation half-life-level environmental variables, during 2012-2019: - Source publication volume: 2/9 coefficients

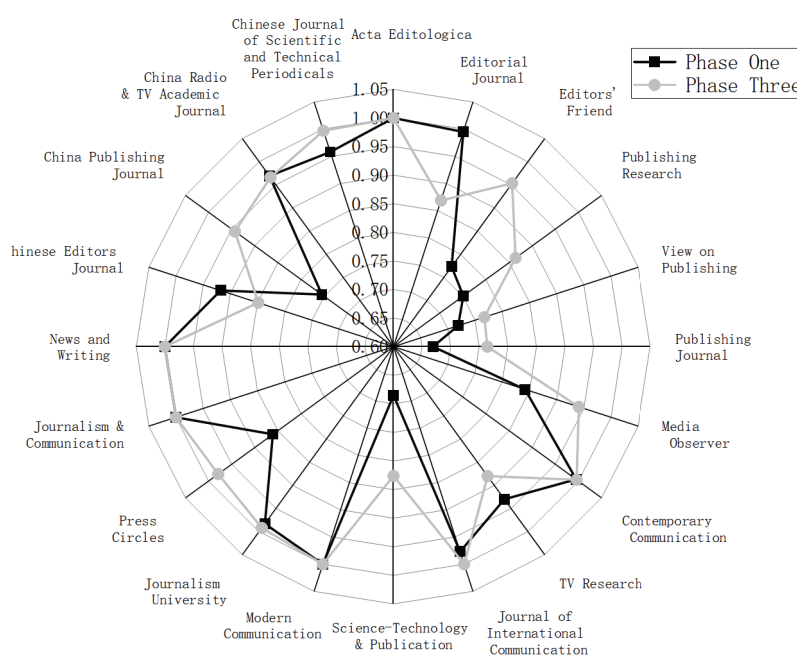
were positive, 7/9 were negative; - Average citation count: 2/9 coefficients were positive, 7/9 were negative; - Funded paper ratio: 3/9 coefficients were positive, 6/9 were negative. Overall, 25.93% of changes were positive and 74.07% were negative, indicating that citation half-life primarily exerts a positive influence on source document volume, average citation count, and funded paper ratio. This suggests that classic theories and methods receive sustained citation over time, with journal articles undergoing extensive validation and recognition.

Regarding the journal age dimension, during 2012-2019, the coefficients for environmental variables showed positive effects in 4/9 cases and negative effects in 5/9 cases for source document volume; positive effects in 5/9 cases and negative effects in 4/9 cases for average citation count; and positive effects in 5/9 cases and negative effects in 4/9 cases for funded paper ratio. This pattern indicates alternating positive and negative impacts over time. Further analysis reveals that negative values predominantly occurred between 2016 and 2019, indicating that insufficient publication history adversely affects journals. Over time, the “time dividend” accumulated through long-term development becomes a positive influence.

### 3.3 Comparative Analysis of Three-Stage Results

After controlling for random and external environmental factors, this study compares the results from the first stage with those from the third stage. Regarding comprehensive technical efficiency, the differences between the first-stage DEA comprehensive technical efficiency values and the third-stage values are illustrated in Figure 1. Among the three-stage comprehensive efficiency values for each journalism and publishing academic journal, the journals *Acta Editologica*, *Modern Communication*, *Journalism & Communication*, and *News and Writing* consistently achieved a comprehensive efficiency value of 1, indicating full DEA efficiency. The comprehensive efficiency values for the remaining journals ranged between 0.8 and 1. Compared to the first-stage comprehensive efficiency values, the comprehensive efficiency values for *Editorial Journal*, *TV Research*, *Chinese Editors Journal* and *China Radio & TV Academic Journal* decreased by 12.6%, while *TV Research*, *Chinese Editors Journal*, and *China Radio & TV Academic Journal* saw minimal declines of less than 7%. The comprehensive efficiency values of *Modern Communication*, *Journalism & Communication*, and *News and Writing* remained unchanged, while the remaining journals all increased, with growth ranging from 0.1% to 20%.

Figure 1 Comparison of Overall Efficiency Values Between Phase 1 and Phase 3

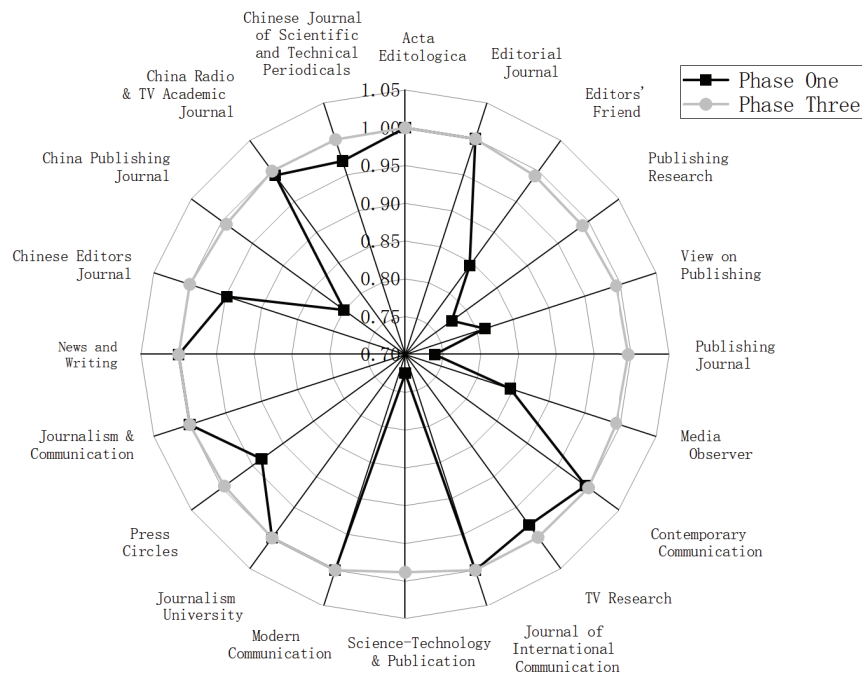


In terms of pure technical efficiency, after the second-stage adjustment, the differences between the first and third stages are shown in Figure 2. The number of journals with pure technical efficiency of 1 increased from 7 to 8. In the first stage, the average pure technical efficiency values of the following journals were 1: *Acta Editologica*, *Editorial Journal*, *Journal of International Communication*, *Modern Communication*, *Journalism & Communication*, *News and Writing*. In the third stage, *Contemporary Communication* was newly added with an average pure technical efficiency value of 1. The average



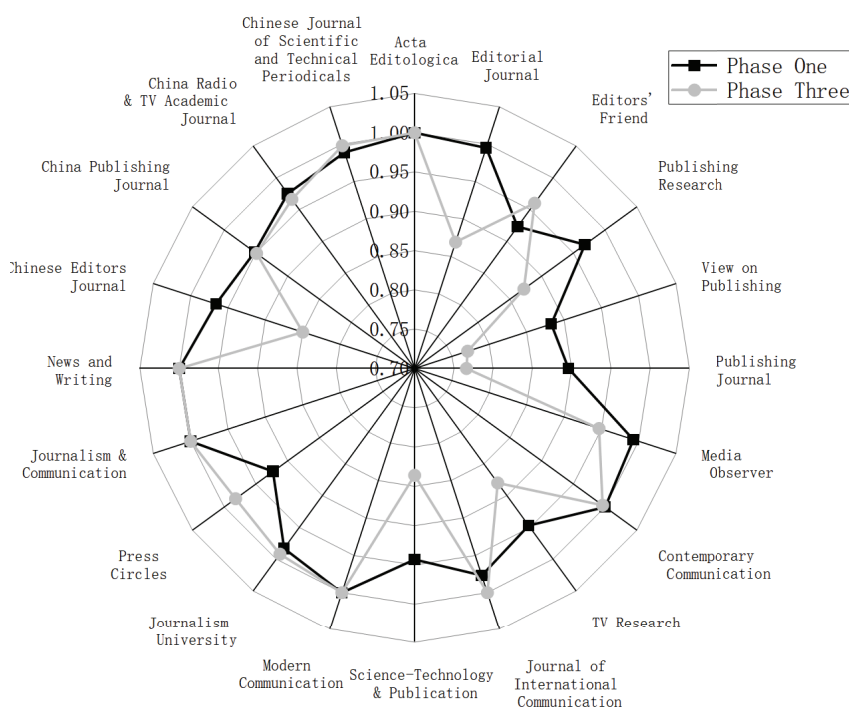
pure technical efficiency values of the remaining journals all fall between 0.99 and 1. Among journals with pure technical efficiency values other than 1, the value of 0.995 is the closest to 1. All pure technical efficiency values have increased, with growth rates ranging from 1% to 30%.

Figure 2 Comparison of Pure Technical Efficiency Values Between Phase I and Phase III



At the scale efficiency level, the differences in efficiency values between the first and third stages are shown in Figure 3. Unlike the changes in overall efficiency and pure technical efficiency, which mostly increased, scale efficiency values fluctuated both upward and downward. Increases ranged from 0.1% to 6%, while decreases spanned from 0.1% to 20%. Some values shifted from efficient to inefficient status. For instance, in the third-stage results, Contemporary Communication's scale efficiency changed from efficient to inefficient.

Figure 3 Comparison of Scale Efficiency Values Between Phase I and Phase III



Phase I and Phase III comprehensive efficiency, pure technical efficiency, and scale efficiency all exhibit changes. After controlling for environmental factors, pure technical efficiency shows an overall improvement. Regional distribution, citation half-life, and publication duration influence journal efficiency, indicating that environmental factors affect the efficiency evaluation of core journals in journalism and publishing, primarily exerting a negative impact.

## **4. Research Conclusions and Recommendations**

### **4.1 Research Conclusions**

Through stage-one and stage-three empirical analysis, journals were classified based on the magnitude of changes in their efficiency values as follows: During the study period, journals maintaining consistent DEA validity and sustained optimal input-output structures were classified as high-efficiency journals. Journals exhibiting efficiency fluctuations due to environmental changes were categorized as environmentally sensitive journals. Beyond these high-efficiency journals, the remaining 16 journals demonstrated significant room for improvement even after controlling for environmental factors, with knowledge exchange efficiency remaining persistently low. These were classified as low-efficiency journals.

#### **4.1.1 Environmental Factors Impact Journal Efficiency**

The coefficient for regional dispersion (77.78%) is positive, indicating that greater geographical dispersion among news and publishing journals leads to increased input wastage and higher management costs. Appropriately reducing actual DMU inputs can partially mitigate environmental dividends. The citation half-life coefficient predominantly exhibits negative values, indicating that this factor inhibits the efficiency of news and publishing journals. The coefficient for publication duration shows non-linear, alternating positive and negative changes, reflecting significant differences in the lifecycles of various news and publishing journals.

#### **4.1.2 Significant Performance Differentiation in Journal Comprehensive Efficiency**

After three-stage adjustments, the four high-efficiency journals—Acta Editologica, Modern Communication, Journalism & Communication, and News and Writing—maintained DEA efficiency throughout the study period. This indicates their input-output structures consistently remained optimal, unaffected by environmental factors. The remaining 16 low-efficiency journals remained inefficient throughout the study period, indicating substantial room for improvement even after controlling for environmental factors. This pronounced divergence reflects significant disparities in operational management and resource allocation among different journals.

#### **4.1.3 Diverse Efficiency Improvement Pathways for Different Journal Types**

Comparing Phase I and Phase III, the efficiency values of environmentally sensitive journals—Editorial Journal, TV Research, Chinese Editors Journal and China Radio & TV Academic Journal—declined, indicating their reliance on environmental factors. Further analysis suggests that optimizing scale development is a viable strategy for these journals to enhance efficiency. In contrast, journals like Editors' Friend, Publishing Research, View on Publishing, and Publishing Journal saw increased efficiency scores, demonstrating that optimizing environmental factors significantly enhances the overall efficiency of these journals.

### **4.2 Policy Recommendations**

#### **4.2.1 Promote Benchmark Journal Management Practices and Establish an Efficient Journal Alliance**

Using four consistently high-efficiency journals like Acta Editologica as benchmarks, conduct in-depth analyses of their strengths in topic planning, digital peer review, and source maintenance. Establish an alliance of high-efficiency journals, distilling their management models into standardized templates for dissemination to other publications. Implement regular exchanges to jointly discuss and adjust topic directions based on academic trends and industry developments, avoiding homogenized competition while promoting efficient knowledge exchange and sharing among journals to enhance overall knowledge dissemination efficiency.

#### **4.2.2 Overcoming Environmental Constraints and Innovating Management Approaches**

For environmentally sensitive journals, establish regional hubs at central locations to optimize resource allocation. Vigorously promote innovative management methods like “online cloud editing,” utilize big data to generate “data radar charts” for

decision support, and implement digital management dashboards for real-time monitoring of process efficiency. These measures break external constraints on journal knowledge exchange, achieve optimal efficiency, and accelerate knowledge dissemination and exchange.

### 4.2.3 Advancing Multi-Faceted Reforms for Persistently Inefficient Journals

Journals with chronic inefficiency must redefine their academic mission, identify specific causes of sustained low productivity, and implement concrete solutions. Content-wise, establish a problem-oriented production mechanism focused on cutting-edge issues to generate high-quality academic outputs and attract superior knowledge exchange. In management development, prioritize cultivating editorial teams' academic judgment and topic planning capabilities while maintaining close ties with academia and industry to proactively solicit high-quality submissions. In response to external changes, conduct in-depth analyses of market demands and institutional strengths, actively participate in refining academic evaluation systems, closely monitor policy and regulatory shifts, and promptly adjust journal operational strategies.

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## Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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# A Study on Logistics Efficiency in the Yangtze River Economic Belt Based on a Three-Stage DEA Model

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**Abstract:** This study employs a three-stage Data Envelopment Analysis (DEA) model to measure and evaluate logistics efficiency in the Yangtze River Economic Belt based on data from 11 provinces and municipalities covering the period 2012–2023. Results indicate that logistics efficiency in the Yangtze River Economic Belt exhibits an overall upward trend; however, development imbalances persist among the upstream, midstream, and downstream regions. Shanghai and Jiangsu exhibit the highest comprehensive technical efficiency, while Chongqing and Sichuan demonstrate the lowest. ② SFA regression analysis reveals that managerial inefficiency is the primary factor causing input redundancy in logistics. The two environmental variables selected—R&D expenditure and regional GDP—exert differing levels of influence on input redundancy. ③ After controlling for environmental variables and random factors, the comprehensive technical efficiency of logistics industries across provinces and municipalities exhibited varying degrees of change. To further enhance logistics efficiency in the Yangtze River Economic Belt, it is essential to strengthen infrastructure development, introduce advanced technologies, and promote regional cooperation to foster coordinated development across the economic belt.

**Keywords:** Yangtze River Economic Belt; Logistics Efficiency; Three-stage DEA Model

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## 1.Introduction and Literature Review

In October 2023, General Secretary Xi Jinping emphasized at the symposium on further promoting high-quality development of the Yangtze River Economic Belt that efforts should be intensified to advance its high-quality development, thereby better supporting and serving China's modernization <sup>[1]</sup>. To propel the development of the Yangtze River Economic Belt, it is essential to leverage its geographical advantages, build a robust logistics and distribution system, and enhance connectivity between domestic and international markets. In 2020, at the Eighth Meeting of the Central Financial and Economic Affairs Commission, General Secretary Xi Jinping stressed, "The circulation system plays a fundamental role in the national economy. To build a new development paradigm, we must treat the construction of a modern circulation system as a key strategic task." <sup>[2]</sup> As an inland river economic belt spanning China's eastern, central, and western regions, the Yangtze River Economic Belt is closely linked to the development of the logistics industry and has played a vital role in advancing the logistics and distribution system. To promote high-quality development in logistics, the state has issued and implemented a series

of policy guidelines. In 2017, the 19th CPC National Congress proposed strengthening infrastructure network construction to advance further the development of the logistics industry<sup>[3]</sup>. In 2021, the Special Action Plan for High-Quality Development of Commerce and Logistics (2021-2025) identified promoting logistics standardization, digitization, and intelligentization as one of its key priorities. The 14th Five-Year Plan for Modern Logistics Development, issued by the State Council in 2022, set the fundamental establishment of a modern logistics system by 2025 as a primary objective.<sup>[4]</sup> That same year, the report to the 20th CPC National Congress called for accelerating the development of the Internet of Things, building an efficient and smooth circulation system, and reducing logistics costs. The Third Plenary Session of the 20th CPC Central Committee set forth explicit requirements for improving the circulation system and reducing logistics costs across society, charting the course for modern logistics development. Additionally, the 20th China Logistics Entrepreneurs Annual Conference explored new approaches and pathways for the logistics industry within the framework of Chinese modernization. With strong support from both the state and the industry, China's logistics market has grown substantially. By 2024, the national social logistics turnover reached 360.6 trillion yuan, marking a year-on-year increase of 5.8%. However, alongside its rapid development, the logistics industry also faces constraints imposed by environmental factors and other random variables. According to relevant data from the National Bureau of Statistics' Statistical Bulletin on National Economic and Social Development, the average annual growth rate of the transportation, warehousing, and postal services sector over the past five years has been 5.4%, while China's GDP has grown at an average annual rate of 5.5%. This indicates sustained high-speed development in China's logistics industry, which plays a crucial role in the country's national economic growth. Over the same period, the logistics sector in the Yangtze River Economic Belt achieved an average annual GDP growth rate of 8.42%, surpassing the national average. This indicates the sustained recovery and positive trajectory of the regional economy within the Yangtze River Economic Belt. Its development aligns with China's logistics industry policies while simultaneously propelling the advancement of modern logistics. Consequently, researching the efficiency of the logistics sector in the Yangtze River Economic Belt and proposing feasible recommendations for its development is essential.

Current academic research has extensively examined logistics efficiency and its influencing factors across various dimensions. Building upon the work of Kang, Tie Liang et al.<sup>[7]</sup>, Gong Xue<sup>[6]</sup> employed the DEA-Tobit model to analyze regional logistics efficiency and its determinants in China from 2010 to 2019. The study revealed a pronounced regional disparity in China's logistics sector, characterized by stronger performance in eastern regions and weaker performance in western regions. Liu Huajun et al.<sup>[8]</sup> employed the EBM model, standard deviation ellipses, and Dagum Gini coefficients to study provincial-level logistics efficiency in China, revealing a trend of efficiency concentration in eastern regions. Yin Yang et al.<sup>[9]</sup> employed the Super-SBM model and Malmquist index model to investigate factors influencing logistics efficiency across 41 cities in the Yangtze River Delta region, finding sustained positive development in logistics efficiency within this area. Similarly, Pei Donghui<sup>[10]</sup> employed the DEA model to examine the logistics efficiency of the Guangdong-Hong Kong-Macao Greater Bay Area urban cluster, suggesting that resource utilization in the region's logistics sector remains inadequate and requires further improvement to enhance efficiency. Zhu Taoxing et al.<sup>[11]</sup> employed the DEA-Malmquist index to examine logistics efficiency in the Beijing-Tianjin-Hebei region, revealing significant disparities in logistics performance. Concurrently, scholars have also measured logistics efficiency along the Yangtze River Economic Belt. Guo Jinyong<sup>[12]</sup> assessed the ecological efficiency of logistics systems across 11 provinces and municipalities in the Yangtze River Economic Belt from 2008 to 2019. Zhang Zhijian et al.<sup>[13]</sup> focused on urban logistics efficiency within the Yangtze River Economic Belt, employing a three-stage DEA model to comprehensively evaluate the logistics sector efficiency of 33 cities along the belt from 2008 to 2018. They observed an overall spatial decay pattern characterized by "lower efficiency upstream and higher efficiency downstream." Additionally, other scholars<sup>[14][15]</sup> conducted separate evaluations of logistics efficiency for individual provinces and municipalities.

In summary, existing relevant research has achieved certain progress at various levels. However, in recent years, scholars' selection of data for studying logistics efficiency in the Yangtze River Economic Belt has lacked timeliness, failing to effectively and accurately reflect the development trends of the logistics industry in recent years. Therefore, this paper will select comprehensive panel data aligned with the latest logistics industry policies. It will construct an evaluation indicator system



for the logistics sector in the Yangtze River Economic Belt from 2012 to 2023. Employing a three-stage Data Envelopment Analysis (DEA) model, it aims to more effectively and accurately assess the efficiency of the logistics industry in the Yangtze River Economic Belt. This evaluation will support the goal of achieving high-quality development in the logistics sector within the Yangtze River Economic Belt.

## 2. Logistics Efficiency Measurement Results for the Yangtze River Economic Belt

### 2.1 Measurement Methods

#### 2.1.1 DEA Model

Traditional DEA models merely identify the efficiency frontier to calculate the distance between it and DMUs (Decision-Making Units), thereby evaluating the effectiveness of the selected indicator data. However, this model overlooks the impact of environmental factors and random disturbance errors. Based on this limitation, Fried et al. proposed a three-stage DEA model<sup>[16]</sup>. Incorporating the SFA model in the second stage, it eliminates the effects of environmental factors, random errors, and managerial inefficiency terms. This enables the DEA model to more accurately reflect efficiency values and provide a more robust evaluation of DMUs. The basic steps are as follows<sup>[17]</sup>:

(1) Phase One: Traditional DEA-BCC Model

The CCR model was developed by Charnes, Copper, and others based on the concept of “relative efficiency.” Subsequently, Banker et al. introduced the BCC model by incorporating the assumption of variable returns to scale<sup>[18][19]</sup>. The commonly used CCR model can simultaneously evaluate scale efficiency and technical efficiency, but it assumes constant returns to scale—meaning increases or decreases in production inputs occur at the same proportional rate. Considering the variable returns to scale characteristic of the logistics industry, the input-oriented BCC model is more suitable for evaluating logistics efficiency in the Yangtze River Economic Belt. Therefore, the BCC model for evaluating logistics efficiency in the Yangtze River Economic Belt is established as follows:

$$\left\{ \begin{array}{l} \min[\theta - \varepsilon(\hat{e}^T s^- + e^T s^+)] \\ \sum_{j=1}^n X_j \lambda_j + s^- = \theta X_0, \\ \sum_{j=1}^n Y_j \lambda_j - s^+ = Y_0, \\ \sum_{j=1}^n \lambda_j = 1, \\ \lambda_j \geq 0, j = 1, 2, \dots, n, \\ s^- \geq 0, s^+ \geq 0. \end{array} \right. \quad (1)$$

Using DEAP 2.1 software for solution and calculation, the technical efficiency, scale efficiency, and overall efficiency of logistics in the Yangtze River Economic Belt were obtained through computation. Based on the evaluation criteria for each efficiency measure in DEA, the logistics efficiency assessment results for the Yangtze River Economic Belt were derived. In the constraints,  $j=1, 2, \dots, n$  represents decision units, while  $X$  and  $Y$  denote input and output quantities, respectively. When  $\theta=1$  and  $S^+=S^-=0$ , the decision unit is considered DEA-efficient, indicating full utilization of production resources without redundancy or waste. When  $\theta=1$  but  $S^+ \neq 0$  or  $S^- \neq 0$ , the decision unit is classified as weakly DEA-efficient. If  $\theta < 1$ , it indicates that the decision-making unit is not DEA-efficient.

#### 2.1.2 Stage Two: Constructing the SFA Model

Stage two utilizes the slack variables from stage one as the explained variables, employing a pseudo-SFA regression model to separate the effects of environmental variables and random disturbance factors. Corresponding to the stage one model, an input-type pseudo-SFA regression function is constructed:

$$\begin{aligned} S_{ni} &= f(z_i; \beta_n) + v_{ni} + u_{ni} \\ n &= 1, 2, \dots, N; i = 1, 2, \dots, I; \\ v &\sim N(0, \sigma_v^2), u \sim N^+(0, \sigma_u^2) \end{aligned} \quad (2)$$

$S_{ni}$  represents the slack variable for the  $n$ th input of the  $i$ -th decision unit;  $z_i$  denotes environmental factors;  $\beta_n$  indicates the estimated coefficient for environmental factors;  $v_{ni} + u_{ni}$  represents the mixed error term of the function, with the two components being uncorrelated;  $v_{ni}$  denotes random disturbance, i.e., the impact of random disturbance factors on the input slack variable, and follows a  $v \sim N(0, \sigma_v^2)$  distribution;  $u_{ni}$  represents managerial inefficiency, i.e., the impact of managerial factors on input slack variables, following a  $u \sim N^+(0, \sigma_u^2)$  distribution. After SFA regression, other logistics input quantities are adjusted based on the regression results, using the input quantities of the most efficient decision unit as the adjustment benchmark. The expression is as follows:

$$x_{ni}^A = x_{ni} + [\max(f(z_i; \beta_n)) - f(z_i; \beta_n)] + [\max(v_{ni} - v_{ni})] \quad (3)$$

Here,  $(x_{ni}^A)$  denotes the input adjusted by slack variables;  $(x_{ni})$  represents the input before adjustment by slack variables;  $(\max(f(z_i; \beta_n)) - f(z_i; \beta_n))$  signifies the adjustment for environmental factors;  $(\max(v_{ni} - v_{ni}))$  indicates setting all decision units at the same level [20].

This paper employs the method proposed by Jondrow et al. for estimation, separating it from managerial inefficiency. Drawing on prior research regarding the separation formula for three-stage DEA, it adopts  $\phi$  as the density function and distribution function of the standard normal distribution. The combined error term is defined as  $\varepsilon_i = V_{ni} + U_{ni}$ , with  $\lambda = \sigma_u / \sigma_v$  and  $\sigma^* = \sqrt{(\sigma_u^2 + \sigma_v^2)}$ . This yields the formula for separating managerial inefficiency and random disturbance:  $= \sqrt{(\sigma_u^2 + \sigma_v^2)}$ ,  $\sigma^{*} = (\sigma_u \sigma_v) / \sigma$ . This yields the formula for separating managerial inefficiency and random disturbance:

$$E(\mu|\varepsilon) = \sigma_* \cdot \left[ \frac{\phi(\lambda\varepsilon/\sigma)}{\phi(\lambda\varepsilon/\sigma)} + \frac{\lambda\varepsilon}{\sigma} \right] \quad (4)$$

### 2.1.3 Stage Three: Adjusted DEA Model

This stage requires reanalyzing the adjusted efficiency. Using the SFA model from Stage II, the adjusted DMU input values are reintroduced into the Stage I DEA-BBC model to calculate efficiency scores. The resulting DMU efficiency values represent technical efficiency, stripped of external environmental factors and random errors. These scores provide a more accurate reflection of the development level of the logistics industry in the Yangtze River Economic Belt and identify key factors influencing its development [21].

## 2.2 Construction of Indicator System and Data Sources

The selection of logistics industry efficiency evaluation indicators must prioritize scientific rigor and practicality. By referencing existing research [22][23] and considering the actual conditions of the logistics sector, we constructed efficiency evaluation indicators. Fixed asset investment in logistics and the number of logistics industry employees were chosen as input indicators, while logistics value-added and freight turnover serve as output indicators. Environmental variables include urbanization rate, per capita consumption expenditure of residents, R&D expenditure, per capita GDP, and degree of openness. Raw data for these indicators were sourced from the China Statistical Yearbook (2012–2023) and statistical yearbooks of the 11 provinces and municipalities along the Yangtze River Economic Belt. Specific indicators are detailed in Table 1.

Table 1 : Logistics Industry Efficiency Evaluation Indicators

Indicator Type	Indicator Name	Unit
Input Indicators	Fixed Asset Investment in the Logistics Industry	¥ billion
	Number of Logistics Industry Employees	10,000 persons
Output Indicators	Value Added of the Logistics Industry	¥ billion
	Freight Ton-Kilometers	100 million ton-kilometers
Environmental Variables	R&D Expenditure	¥ billion
	GDP per Capita	¥10,000/person
	Degree of Opening-up	--



## 2.3 Analysis of Measurement Results

### 2.3.1 Phase One Analysis

Using the constructed indicator system and DEA2.1 software, we analyzed input-output data from 2012 to 2023 for 11 provinces and municipalities along the Yangtze River Economic Belt. This yielded logistics efficiency scores and their decompositions for each region, as shown in Table 2 below.

*Table 2 : Average Logistics Efficiency of the Yangtze River Economic Belt, 2012–2023*

Province/City	Efficiency Rank	Overall Technical Efficiency	Pure Technical Efficiency	Scale Efficiency
Shanghai	1	1.000	1.000	1.000
Jiangsu	2	0.978	1.000	0.978
Zhejiang	3	0.962	1.000	0.962
Anhui	4	0.954	1.000	0.954
Jiangxi	5	0.784	0.847	0.926
Hubei	6	0.769	0.932	0.825
Hunan	7	0.750	0.795	0.943
Chongqing	8	0.597	0.647	0.922
Sichuan	9	0.438	0.520	0.843
Yunnan	10	0.391	0.760	0.514
Guizhou	11	0.343	0.371	0.924
Average	—	0.724	0.807	0.890

#### (1) Comprehensive Technical Efficiency Analysis

Table 2 shows the comprehensive technical efficiency of the 11 provinces and municipalities along the Yangtze River Economic Belt from 2012 to 2023. Anhui Province achieved an average comprehensive technical efficiency of 1.000, indicating that its logistics industry has reached an equilibrium state of input-output balance. This represents DEA effectiveness and a high level of logistics efficiency. Among other provinces, Shanghai, Jiangxi, and Guizhou all achieved comprehensive technical efficiency above 0.9 but below 1.000. This indicates that while these three provinces maintained relatively high logistics efficiency levels from 2012 to 2023, their logistics industries did not achieve balanced input-output ratios. Consequently, they were not DEA-efficient, and output efficiency still requires improvement. Jiangsu, Zhejiang, Hubei, and Hunan exhibit relatively high average comprehensive technical efficiency. However, compared to Anhui, Shanghai, Jiangxi, and Guizhou, they have yet to achieve efficient levels, necessitating further optimization of logistics industry inputs and outputs. In contrast, the southwestern provinces of Chongqing, Sichuan, and Yunnan display very low average comprehensive technical efficiency, indicating extremely low logistics efficiency over the past 11 years. Significant improvements in the logistics industry inputs and outputs are required. Based on the overall data, Anhui's logistics industry demonstrates the highest overall development level, while Chongqing, Sichuan, and Yunnan require further development.

#### (2) Pure Technical Efficiency Analysis

Among the 11 provinces and municipalities in the Yangtze River Economic Belt, Shanghai, Anhui, Jiangxi, and Guizhou recorded the highest average pure technical efficiency values from 2012 to 2023, all at 1.000. This indicates that these four regions achieved maximum utilization of technical inputs in their logistics industries, fully leveraging logistics resources. The lowest values were recorded in Chongqing and Sichuan, with pure technical efficiency scores of 0.520 and 0.371, respectively. This may be attributed to both regions being located within the Sichuan Basin, which increases the difficulty of logistics infrastructure development and product transportation, leading to higher costs and greater labor input. Although

Jiangsu, Zhejiang, Hubei, Hunan, and Yunnan did not achieve the highest average pure technical efficiency scores, their efficiency levels were significantly higher than those of Chongqing and Sichuan. These provinces demonstrate more effective utilization of logistics resources and a relatively well-developed technical foundation within their logistics industries.

### (3) Scale Efficiency Analysis

The average scale efficiency values for the 11 provinces and municipalities along the Yangtze River Economic Belt from 2012 to 2023 were generally high. Anhui's average scale efficiency reached 1.000, indicating that logistics enterprises maximized their input-output ratio during production processes, fully leveraging economies of scale. Except for Yunnan, the average scale efficiency values of other provinces all exceeded 0.8, indicating that the input-output ratio of the logistics industry remained at a relatively high level. However, there is still room for optimization and improvement in resource allocation management. Yunnan's average scale efficiency value significantly diverged from other provinces, likely due to its southern border location constrained by geographical conditions and infrastructure limitations. Predominantly mountainous and plateau terrain, coupled with its remote distance from other regions, resulted in high transportation network construction costs and low coverage density. This led to markedly lower logistics efficiency compared to other provinces, hindering cross-regional transportation and the exchange of Yunnan's products. Furthermore, its industrial structure leans toward traditional sectors like agriculture and tourism, with a weak logistics foundation and a small share of advanced manufacturing and high-value-added industries, resulting in low economies of scale. In contrast, downstream provinces, leveraging the Yangtze River Delta urban cluster, have established highly synergistic industrial chain clusters with significant economies of scale. Consequently, Yunnan's economies of scale level falls below that of the other 10 provinces and municipalities.

### 2.3.2 Analysis of Second-Stage Regression Results

The SFA regression analysis indicates (as shown in Table 3) that the Gamma value approaches 1, suggesting that management inefficiency is the primary factor causing input redundancy <sup>[24]</sup>. The regression coefficients for the SFA of the three environmental variables mostly passed the significance level test, indicating that the selected environmental variables—R&D funding, regional GDP, and degree of openness—significantly influence the redundancy of various input factors in the logistics industry. When considering the impact of environmental variables on input slack, examining the sign of regression coefficients reveals the directional relationship between environmental variables and input slack variables. A negative regression coefficient indicates an inverse relationship: an increase in the environmental variable leads to a decrease in input slack and an increase in output value, and vice versa.

Table 3 : SFA Regression Model Results

Name	2015		2018	
Indicator	Fixed Asset Investment Lagging Variable	Number of Employees Lagging Variable	Fixed Asset Investment Lagging Variable	Number of Employees Lagging Variable
Constant	-0.01	0.01	0.00	-0.03
R&D Expenditure	-0.02	-0.02	0.00	0.01
GDP per Capita	0.01	0.01	-0.01	0.00
Degree of openness	-0.03	-0.02	0.03	-0.02
$\sigma^2$	0.01	0.00	0.03	0.00
$\gamma$	1.00	1.00	1.00	1.00
LR	8.79	8.32	6.42	6.86

Note: Due to space constraints, only the SFA regression results for 2015 and 2018 are reported.

Based on the above analysis and incorporating regression analysis results, we further examined the impact of environmental factors, yielding the following findings:

#### (1) R&D Expenditure

Technological advancement appropriately reduces redundant fixed asset investment and workforce in the logistics sector. However, excessive R&D expenditure does not significantly decrease the level of redundancy in the logistics industry investment. Against the backdrop of digital logistics, intelligent logistics, and green logistics, R&D funding has increased significantly across regions. However, the infrastructure required to support these new technologies is massive in scale, with lengthy construction cycles and slow returns on investment. Substantial funding injections will only increase investment redundancy in the logistics sector, hindering its development progress.

## (2) Per Capita GDP

Considering both input indicators, per capita GDP influences both logistics fixed asset investment and logistics employment, but its impact on logistics employment is more pronounced. From 2012 to 2023, the regression coefficients between per capita GDP and input slack variables were all positive, indicating that a decline in per capita GDP leads to an increase in the slack values of logistics fixed asset investment and logistics employment inputs, thereby reducing output.

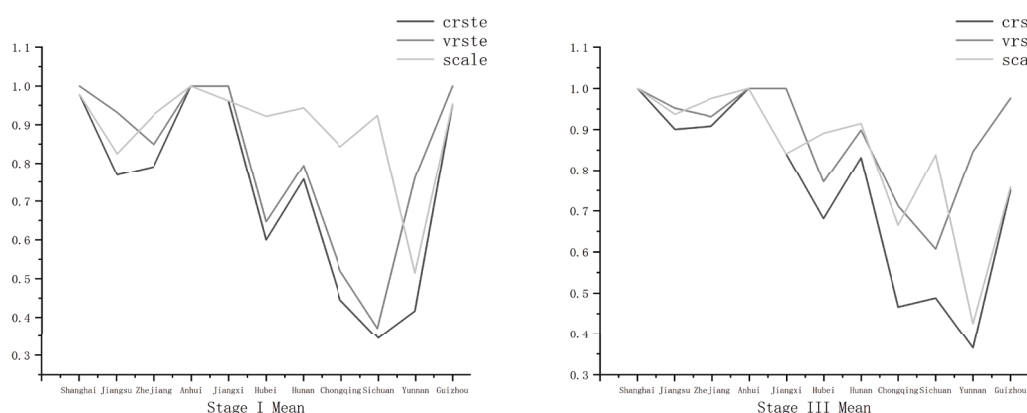
## (3) Degree of Openness to the Outside World

Compared to other environmental variables, the degree of openness to the outside world does not significantly impact input redundancy values, but it does exert some influence. Among the 11 provinces and municipalities in the Yangtze River Economic Belt, regions closer to the east—such as Shanghai, Jiangsu, and Zhejiang—exhibit higher levels of openness to the outside world, with input redundancy values approaching zero. However, analysis of the logistics workforce reveals that Shanghai experienced negative input slack in 2014, 2020, and 2021, while Jiangsu has exhibited this pattern for multiple consecutive years. This indicates that even with a relatively complete system of openness, attention must be paid to the rational allocation and utilization of related input resources; otherwise, resources will be wasted.

### 2.3.3 Third Stage

The input values in the third stage exclude environmental variables and random factors. These adjusted input values replace the original inputs for recalculation, yielding the third-stage results. Comparing the first-stage mean with the third-stage mean produces the findings shown in Figure 1. As illustrated in Figure 1, after eliminating environmental variables and random factors, it becomes evident that environmental variables significantly impact efficiency assessment. After Stage 3 adjustments, upstream provinces demonstrated improvements in overall technical efficiency, pure technical efficiency, and scale efficiency, maintaining their position at the frontier. This indicates that, as economically developed regions, upstream provinces possess relatively mature logistics systems, with R&D funding, per capita GDP, and openness to the outside world effectively supporting efficient resource allocation. Mid-to-downstream provinces showed divergence: Hubei and Hunan saw their adjusted comprehensive technical efficiency rise to 0.681 and 0.832 respectively, indicating efficiency gains after environmental variable correction. Conversely, Jiangxi's comprehensive technical efficiency plummeted from 1.0 to 0.841, revealing that its original efficiency partially relied on environmental advantages (such as higher openness), exposing shortcomings in actual management effectiveness. However, Chongqing, Sichuan, and Yunnan remain at low levels. Notably, Yunnan's comprehensive technical efficiency declined from 0.416 to 0.365, reflecting that its logistics sector is constrained by insufficient R&D investment or low openness, with scale efficiency severely dragging down overall performance.

Figure 1 Comparison of Mean Values Between Phase I and Phase III



### 3. Conclusions and Recommendations

#### 3.1 Key Findings

(1) Research indicates that logistics industry efficiency in the Yangtze River Economic Belt is generally on an upward trend. However, development remains uneven across upstream, midstream, and downstream regions. Downstream regions exhibit the highest logistics efficiency, followed by midstream regions, with upstream regions ranking lowest. Among provinces, Shanghai and Jiangsu demonstrate the highest overall technical efficiency, influenced by various factors. Zhejiang, Anhui, Jiangxi, and Hunan follow, while Chongqing and Sichuan rank lowest.

(2) SFA regression analysis indicates that managerial inefficiency is the primary factor causing input redundancy. Among environmental variables, R&D expenditure, per capita GDP, and openness to foreign trade significantly influence input redundancy across logistics sectors. Results show that reasonable R&D investment promotes stable logistics development, whereas excessive funding increases input redundancy and hinders progress. Increases in per capita GDP also reduce input redundancy in fixed asset investment and labor input within the logistics sector, thereby boosting output growth. Among environmental factors, the degree of openness has a relatively minor impact on input redundancy.

(3) After controlling for environmental variables and random factors, Upstream provinces exhibit significantly higher comprehensive technical efficiency, indicating that their high R&D investment and openness levels effectively reduce input redundancy through technological upgrading and management optimization; Central provinces exhibit smaller efficiency fluctuations, reflecting an “extensive inertia” stemming from the contradiction between their per capita GDP and technological level. Downstream provinces, however, experience declining adjusted efficiency due to weak economic foundations and insufficient R&D support, exposing structural imbalances between scale investment and output.

#### 3.2 Recommendations

##### 3.2.1 Strengthen Infrastructure Development

Analysis indicates that transportation infrastructure in certain regions remains underdeveloped. The 11 provinces and municipalities along the Yangtze River Economic Belt should optimize navigation channels to enhance waterway capacity; strengthen port facilities to improve cargo throughput efficiency; and expand highway and railway networks to establish a multimodal transport system. Regions with relatively low efficiency, such as Chongqing and Sichuan, should prioritize optimizing resource allocation for the logistics sector and developing logistics warehousing sites to boost overall efficiency.

##### 3.2.2 Introducing Advanced Technologies

Provinces and municipalities such as Shanghai, Jiangsu, and Zhejiang possess objectively high logistics efficiency. They can continue leveraging their geographical and technological advantages by rationally applying modern information technologies like the Internet of Things, big data, and cloud computing to enhance logistics management standards and explore the development of smart logistics. Provinces and cities in the “Two Lakes” region should learn from the practices of logistically efficient areas, adapting measures to local conditions—such as streamlining administrative procedures, lowering barriers and costs for logistics operations, and attracting more leading logistics enterprises from eastern regions. Provinces and cities in the “Two Yangs” region need to optimize the business environment, gradually reducing the interference of environmental variables and random factors on logistics development.

##### 3.2.3 Promoting Regional Cooperation

The 11 provinces and municipalities along the Yangtze River Economic Belt can leverage better-developed regions as a foundation. By facilitating exchanges among logistics professionals and organizing specialized conferences on industrial development, they can promote multidimensional talent mobility, achieving a positive “mentoring and assistance” effect for logistics sector growth. Provincial governments can break down cross-regional policy barriers through favorable incentives, offering tax breaks and financial support to regional logistics enterprises, thereby fostering coordinated development across the Yangtze River Economic Belt.

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## Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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# From Willingness to Pay to Behavioral Prediction: Exploring the Interconnection among CVM, CE, and PLS-SEM

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**Abstract:** This article reviews three related methods extensively used in non-market valuation research, namely, contingent valuation method (CVM), choice experimental method (CE) and partial least squares structural equation model (PLS-SEM). CVM measures the maximum monetary amount of willingness to pay (WTP) that people are willing to pay for non-market goods, CE analyses the preference trade-offs at the attribute level, and PLS-SEM explores the potential psychological mechanism underlying behavioral intention. This article refers to recent cross-disciplinary research to trace the historical process of development, complementarity of methods and integration of theories.

This article believes that the integration of CVM, CE and PLS-SEM has entered a new stage in valuation research, it goes beyond the static monetary valuation and turns to a behavioral valuation path that connects economic, cognitive and social aspects of decision-making. This article discusses the convergence of methodology, as well as the challenges in data compatibility, sampling requirements and differences in model assumptions. In addition, this article also focuses on the future research direction, including hybrid survey design, data integration and interdisciplinary theoretical expansion. Finally, this article advocates establishing an empirical framework to predict and explain public preferences in the field of heritage and environment. Even if it is impossible to make direct policy adjustments, such as price adjustment, this comprehensive assessment model can still play a predictive and strategic role, thus providing decision-makers with an empirical basis for sustainable and inclusive management.

**Keywords:** CVM; CE; PLS-SEM; Non-market Valuation Model; Behavioral Economics; Total Economic Value

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## 1. Introduction

In economics, the short-term market value of commodities is determined by supply and demand, while their long-term economic value reflects the intrinsic utility and social utility of commodities<sup>[1]</sup>. Based on this distinction, the concept of total economic value (TEV) is usually broken down into two parts: use value and non-use value. Use value includes the direct and indirect benefits of consumption or ecosystem services, while non-use value covers the legacy value and existential value that reflect moral, cultural or intergenerational factors.

When a commodity cannot be traded in the traditional market - such as clean air, natural landscape or cultural heritage - its value must be inferred through a non-market valuation model. Among them, the Contingent valuation method (CVM) has become the main method for estimating individuals' willingness to pay for intangible commodities based on the principle



of utility maximization<sup>[2]</sup>, CVM assumes that rational individuals seek utility maximization under their own preferences and income constraints<sup>[3]</sup>.

However, although the contingent valuation method (CVM) can determine the monetary upper limit of willingness to pay (WTP), it cannot explain the psychological or behavioral mechanism behind willingness. What the determinants of satisfaction are, whether it is caused by the attributes of goods or past experience, is still unknown. To make up for the deficiency of CVM, the determinants of satisfaction are still unknown, the Choice experiment (CE) and the partial least squares structural equation model (PLS-SEM) are used to complement the research. The CE analyzes the preference trade-offs at the attribute level of multiple products, and PLS-SEM explores the potential cognitive and attitude factors that affect behavioral intention. These two methods are integrated to have a better understanding of how people value non-market commodities and then connect the economic estimates and behavioral intentions.

Early questionnaire valuation research usually adopted a single methodological framework, such as CVM or travel cost method (TCM). With the development of research paradigm, scholars are gradually focusing on a comprehensive approach, that is, two or more models are integrated into one survey design<sup>[4]</sup>. For example, some scholars combined the CVM with the CE to measure the overall WTP and the preference at the attribute level at the same time<sup>[5][6]</sup>; or combined the CE with the partial least squares structural equation model (PLS-SEM) to integrate the preference of the statement and the potential psychological mechanism<sup>[7]</sup>.

However, the research on combining CVM with PLS-SEM is still lacking. The theoretical gap in this research direction provides a promising prospect for future research, because this integration can connect the monetary valuation of commodities and the behavioral and cognitive aspects of individual decision-making.

As mentioned above, there are limitations in each of valuation models. Researchers continue to attempt to overcome these limitations by developing new methods. For instance, CVM is weak in explaining the psychological mechanisms underlying the behavior of choice<sup>[8]</sup>. However, PLS-SEM can compensate for this limitation by identifying other structures that influence the willingness to pay (such as attitude, trust or perceived value). Similarly, CE can make up for the limitation of CVM in explaining the multi-attribute trade-offs in order to gain deeper understanding of how people make trade-offs among the various characteristics of commodities<sup>[9]</sup>.

In recent years, these mixed questionnaire models have been used more and more widely in interdisciplinary fields such as tourism, environmental management and education, reflecting the broader trend of combining economic value assessment with behavioral analysis<sup>[10]</sup>.

Although methodological progress has been made in recent decades, the research on CVM, CE and PLS-SEM is still limited and scattered. The lack of a unified framework limits the potential for a comprehensive capture of economic and behavioral dimensions of non-market value assessment. Therefore, this article aims to integrate the evolution, complementarity and integrity of these three methods, focusing on their theoretical connection and empirical application. By systematically examining the interaction of CVM, CE and PLS-SEM, this paper strives to build a unified behavioral value evaluation perspective to link monetary estimation, preference structure and cognitive mechanism. The following chapters will introduce the evolution of the value assessment model, explore the conceptual interconnection, and put forward the research direction to promote interdisciplinary applications in the fields of environmental and cultural economics in the future.

## **2. Evolution of Valuation and Behavioral Analysis Methods**

### **2.1 The Rise of Stated Preference Techniques**

Under the framework of overall economic value (TEV), valuation methods can be roughly classified into two categories: revealed preference (RP) and stated preference (SP) technology. The display preference method depends on the observed market data and existing price information to infer individuals' valuations of commodities. For example, TCM uses the actual travel time and cost of tourists to estimate the leisure value of scenic spots. The pleasure pricing model infers the value of environmental attributes by relying on the changes of property or wage data.

In contrast to the declarative preference method - including CVM and CE - which is applicable to goods and services with prices<sup>[11]</sup>, the method is designed for goods and services without market prices. Therefore, the declarative preference

method depends on hypothetical situations and simulated market to draw out the psychological expectations and preferences of respondents. By asking how people will do or how much they are willing to pay under the hypothetical condition, the declarative preference method can draw out the subjective values and preference of respondents and further understand individuals' preferences for non-market commodities such as environmental quality, cultural heritage or ecosystem services.

## 2.2 Contingent Valuation Method (CVM): From Monetary Value to Behavioral Intent

CVM is one of the most widely used methods of expression of will<sup>[12]</sup>. It constructs a hypothetical market that requires respondents to express their maximum willingness to pay (MWTP) for maintaining, improving or obtaining a non-market commodity. Through this mechanism, CVM transforms psychological preferences into monetary value, thus directly linking economic welfare theory with behavioral response<sup>[13]</sup>.

A) Initial quotation question: "Are you willing to pay X (initial quotation) for the proposed improvement or project?"

B1) Subsequent higher quotation questions: If the respondents answer "yes" to the initial quotation, they will be asked if they are willing to pay a higher offer (for example,  $X + \Delta$ ).

B2) Subsequent lower quotation questions: If the respondents answer "no" to the initial quotation, they will be asked whether they are willing to pay a lower quotation (for example,  $X - \Delta$ ).

C) Maximum willingness to pay (MWTP) problem - this is the core of the CVM which requires respondents to determine the maximum amount they are willing to pay before refusing further payment.

The MWTP derived from these answers represents the upper limit of perceived economic value and serves as the basis for estimating the average or med-level willingness of the population to pay.

In order to ensure statistical validity, researchers usually design multiple initial bids (for example, 10 yuan, 15 yuan, 20 yuan) and randomly allocate these bids in different survey versions. This diversity allows researchers to use econometric models such as logit, probit or interval regression in software such as STATA to estimate, so as to obtain a continuous distribution of willingness to pay, rather than a single point estimate.

Although the CVM has certain practicality, it still faces the following persistent challenges:

I) Hypothetical bias - because the payment is not real, respondents may overestimate or underestimate their willingness to pay (WTP);

II) Starting point deviation and anchoring effect - the initial bid will affect the willingness of the respondents to pay;

III) Strategic bias - individuals may deliberately distort their preferences to affect the results;

IV) Information and understanding effect - participants' understanding of the situation will affect the reliability of the answer;

V) Lack of insight at the attribute level - CVM provides the overall value, but it cannot reveal which specific attributes drive this valuation.

These limitations have prompted people to develop more sophisticated methods, especially the CE model. CE expands the scope of application of CVM by decomposing commodities into their constituent attributes and presenting a variety of alternative combinations to respondents. This allows researchers to estimate the marginal willingness of each attribute and analyze the trade-offs in individual preferences - thus overcoming the static and holistic defects of traditional CVM.

## 2.3 Choice Experiments (CE): The Multi-Attribute Evolution of Preference Measurement

The Choice experiment (CE) method is a major methodological progress within the framework of the Discrete Choice model (DCM)<sup>[14]</sup>. Unlike the CVM, which focuses on obtaining a single maximum willingness to pay (MWTP), CE allows respondents to evaluate multiple hypothetical options, each of which consists of a series of attributes and their levels.

In a typical CE design, respondents will see several selection cards, each showing two or more options (for example, protection projects, travel packages or environmental improvement programs), which are defined by different attribute sets, such as price, accessibility, cultural value and environmental quality. Participants need to choose their preferred options in each situation, so as to reveal their trade-offs between different attributes. This mechanism captures the preferred multi-dimensional structure, so that the marginal willingness to pay (MWTP) of each attribute can be estimated through the logical regression model or the mixed logical regression model<sup>[15]</sup>.

Including price in one of the attributes enables CE to generate an economic value estimate equivalent to conditional value

assessment CVM. In practice, researchers usually use the price level obtained from the initial bid of CVM as the monetary attribute in CE design, thus establishing a direct connection between the two methods<sup>[16]</sup>. In this sense, CE is a supplementary extension of CVM: CVM measures the overall value of commodities, and CE breaks down the value into the contributions of each attribute, thus providing more detailed and policy-related insights.

However, although CE can capture how individuals weigh between different characteristics, it cannot explain why these choices occur - what is the cognitive or attitude mechanism that drives these behaviors<sup>[17]</sup>. This limitation prompted researchers to introduce the partial least squares structural equation model (PLS-SEM) as an analysis extension. By integrating potential structures such as attitude, trust, satisfaction and perceived behavior control, PLS-SEM can model the psychological path behind the statement selection and transform behavioral data into a more comprehensive cognitive-behavioral value assessment framework.

## **2.4 Partial Least Squares Structural Equation Modeling (PLS-SEM): Explaining the Cognitive Mechanism**

Partial least squares structural equation model (PLS-SEM) is a variance-based statistical technique used to test the relationship between potential structures - usually involving independent variables, intermediary variables and dependent variables. In the field of non-market valuation and behavioral research, PLS-SEM is particularly suitable for building attitude-intention-behavior association models and identifying psychological mechanisms that affect individual preferences and willingness to pay<sup>[18]</sup>.

Compared with the covariance-based structural equation model (CB-SEM) aimed at reproducing the observational covariance matrix and evaluating the fit of the model, PLS-SEM focuses on maximizing the explanatory variance ( $R^2$ ) of dependent variables, emphasizing prediction rather than verification<sup>[19]</sup>. This predictive orientation is highly in line with the goal of valuation research, because valuation research aims to understand how various psychological and situational factors affect behavioral intentions, rather than verifying a fixed theoretical model.

Another practical advantage of PLS-SEM is its flexibility in data distribution and sample size. CB-SEM requires a large sample size and assumes a multivariate normal distribution, and these conditions are often difficult to meet in field surveys such as environmental or tourism research. In contrast, PLS-SEM does not have a strict distribution hypothesis and can run steadily even in small and medium sample sizes ( $n = \text{number of projects} * 10$ ), making it a better choice for exploratory or predictive research<sup>[20]</sup>.

In addition, PLS-SEM allows the estimation of the measurement model (the relationship between the potential structure and its indicators) and the structural model (the relationship between the structure) at the same time<sup>[21]</sup>, thus providing reliability diagnosis and hypothesis testing within a single framework. This double-layer model capability enables researchers to quantify abstract psychological variables (such as attitude, trust, perceived value and satisfaction) and assess how these structures together affect behavioral intent and actual behavior.

## **3. Integrating CVM, CE, and PLS-SEM: Toward a Unified Behavioral Valuation Framework**

### **3.1 Theoretical Complementarity and Hierarchical Logic**

CVM, CE and PLS-SEM constitute a complementary methodological level. They link economic value assessment, behavioral choice and psychological cognition together. Each of them represents different behavior in the process of decision-making. It helps to understand the individuals' preference for non-market commodities more deeply.

At the first level, CVM can be seen as a dominant currency threshold. It is the price that individuals are willing to pay for the proposed goods or services. It directly expresses value in money. However, it is only the result of superficial behavior<sup>[22]</sup>.

At the second layer, the CE extends this idea to break down commodities into multiple attributes and attribute levels. Respondents are allowed to trade-off between competing characteristics. Through the preference measurement of commodity attributes and attribute levels, CE reveals the composition of value (which cannot be identified by CVM). This result enriches the interpretation of consumer heterogeneity and marginal utility<sup>[23]</sup>.

At the third level, PLS-SEM goes beyond measurable preferences and examines possible cognitive drivers - such as attitude,

trust, satisfaction or perceived behavior control - which explain the existence of the above decision-making. PLS-SEM explains why people value or choose the alternatives and connects economic behavior and psychological intentions to form an integrated causal structure. From a mathematical point of view, using PLS-SEM also relaxes the restrictive assumptions inherent in the traditional DCM. In particular, CE is typically based on the assumption of independence of irrelevant alternatives (IIA), which is often not satisfied in real-world decision-making situations<sup>[24]</sup>. The common ways to overcome this problem include applying nested Logit (NL) or mixed Logit (ML) or PLS-based structural methods. The latter provides a more flexible way to model the heterogeneity and the related decision-making behavior.

Generally speaking, these three methods can form a hierarchy of value evaluation: CVM describes the price threshold of the selection, CE explains the structural trade-offs within the selection, and PLS-SEM reveals the production mechanism of the choice is born. This multi-level logic not only adds depth to the system, but also ensures its coherence, allowing researchers to move from descriptive value evaluation to a predictive and explanatory view of human behavior in non-market situations.

### 3.2 Empirical Integration and Application Pathways

Although CVM, CE and the PLS-SEM come from different analytical traditions, they can be logically integrated to gain a more comprehensive understanding of value assessment and behavior. In empirical studies, these models are typically applied sequentially and are rarely applied in combination directly. Each method is applied at a different level of analysis.

In this integrated path, CVM is typically used to estimate the willingness to pay for certain policies or non-market commodities (WTP) and therefore provides a real indicator of economic preferences. Although the WTP value cannot be used as a dependent variable directly in PLS-SEM (because PLS-SEM is focused on modeling behavioral intentions and actions rather than numerical results), it conceptually represents the external manifestation of potential attitudes and motivations. Thus, PLS-SEM complements CVM by explaining why individuals express certain preferences and attitudes and finds cognitive and emotional determinants that cause the emergence of observed value evaluation patterns.

Similarly, CE creates a bridge between value evaluation and cognition by embedding psychological factors such as attitude, satisfaction or perceived value in the experimental design. Cognitive engineering allows respondents to choose from multi-attribute options and therefore captures behavioral trade-offs that reflect deeper motivational structures, which are then analyzed by PLS-SEM to find their potential causal path.

In recent years, such integrated multi-method frameworks have been increasingly applied in cross-disciplines such as heritage management<sup>[25]</sup>, tourism<sup>[26]</sup> and environmental<sup>[27]</sup>, which indicate that the economic value assessment can not be totally comprehended without combining behavioral and psychological aspects in recent years. Combined with these methods, we can have a more comprehensive understanding of how people evaluate and treat non-market commodities in two aspects and multiple levels.

### 3.3 Challenges and Future Directions

Although it has become increasingly popular to combine CVM, CE and PLS-SEM into one analytical framework, some methodological challenges still exist. The first challenge is adjustment of sample size. Each method has its own requirement of data. It is always difficult for researchers to combine them together. In practice, the overall sample size is usually determined by the most demanding of the three models. However, this method will complicate the process of survey and raise higher requirements for data collection, which will increase the cost of data collection<sup>[28]</sup>.

The second challenge exists in the difference of model assumptions. CVM and CE are based on the principle of utility maximization and assume that individuals will make rational economic choice. However, PLS-SEM is based on the behavior prediction paradigm and focuses on possible psychological structure and path relationships. In order to make these contradictory theoretical foundation to reach a certain level of consistency, researchers should be careful in constructing concepts.

Another practical problem exists in the compatibility of design. As for the second challenge, since the combination of valuation and behavioral measurement items will make the questionnaire too long and even increase the degree of fatigue of respondents<sup>[29]</sup>, researchers can choose to distribute related questionnaires to different groups of respondents. This method

can reduce the cognitive burden of respondents and maintain the statistical correlation between two groups of respondents through common demographic and attitude variables.

In the future, the combination of hybrid questionnaires and multi-layer model framework can be used to integrate valuation results and behavioral structure into one framework. Such innovation will increase the flexibility of analysis and depth of interpretation and promote the integration of economic aspect and psychological aspect in non-market valuation research.

## 4. Research Gaps

### 4.1 Theoretical Expansion and Interdisciplinary Connection

The theoretical range of non-market valuation has traditionally been limited in welfare economics and utility maximization, where human behavior is assumed to be rational and self-interest. However, with valuation research increasingly focusing on complex socio-cultural and environment context, this model cannot explain all motivations of people's preferences and behaviors. Therefore, future studies should attempt to extend the current economic rationality theory and expand interdisciplinary theoretical range, which can include interdisciplinary theoretical perspectives that reflect emotional, social and moral aspects.

In this regard, the direction of theoretical expansion usually varies according to the orientation of the discipline. For example, environmental management research can refer to the value-belief-norm (VBN) and planned behavior theory (TPB) frameworks and use them to link personal norms and perceived behavior control with the will to protect. In the study of tourism and cultural heritage, theories such as location attachment, identity reconstruction and symbolic consumption can offer richer insights into how meaning, memory and cultural resonance affect willingness to pay or travel again<sup>[30]</sup>. In the field of education and social policy, models that emphasize trust, social capital and equity can reveal the collective or altruistic motives contained in value judgment<sup>[31]</sup>.

Theoretical scope of non-market value assessment is traditionally founded on welfare economics and utility maximization models in which human behavior is modeled to be rational and self-interested. However, when value assessment studies consider the social, cultural and environmental context involved, this model has been proven inadequate to explain all of the personal preference and behavior motivations. Therefore, future research should attempt to transcend economic rationality and expand into interdisciplinary theoretical extension to reveal the social and moral dimensions of value assessment and the emotional motivations behind them.

In this regard, the direction of theoretical expansion usually varies according to the orientation of the discipline. For example, environmental management research can refer to the value-belief-norm (VBN) and planned behavior theory (TPB) frameworks and use them to refer to the link between personal norms and perceived behavior control with the will to pay. In the field of tourism and cultural heritage, theories such as location attachment, identity reconstruction and symbolic consumption can offer richer insights into how meaning, memory and cultural resonance affect willingness to pay or travel again<sup>[30]</sup>. In the field of education and social policy, models that emphasize trust, social capital and equity can reveal the collective or altruistic motives contained in value judgment<sup>[31]</sup>.

However, any attempt at theoretical integration must first ensure its feasibility and empirical coherence. The introduction of concepts from other fields should be based on clearly conceptualized definitions, reliable measurement indicators and sufficient data structures so as to avoid an excessive mixing and matching of concepts. In this sense, theoretical extension is not just to introduce concepts from other fields but to establish a coherent causal extension and apply it to empirical models such as PLS-SEM.

Through the combination of theoretical diversity and the feasibility of methodology, future research should build an assessment framework that links economic value assessment with the psychological and socio-cultural basis of choice.

### 4.2 Toward Evidence-Based Heritage and Environmental Valuation

Despite the methodological and theoretical advances mentioned above, the practical application of non-market valuation results toward policy and management is still weak. Future research should therefore attempt to build valuation evidence-based frameworks that can directly inform heritage conservation and environmental decision-making. By establishing the link between behavioral insights and economic estimation, this kind of framework can assist policymakers to design



pricing mechanisms and conservation incentives as well as communication strategies based on empirical evidence instead of assumption.

However, the way forward to evidence-based practice is not homogenous for all disciplines. Theoretical expansion and methodological feasibility depend on the research context. For instance, the valuation of heritage management should comply with the cultural policy context and emphasize authenticity, public engagement and identity. Theoretical expansion for the valuation of heritage management should also consider the feasibility of the method and empirical applicability, that is, the feasibility of measuring and applying the concept proposed.

Although the development of methods and theory have enhanced people's understanding of non-market value, their application in practice for policy-making is still limited. Future research should aim at establishing an evidence-based value assessment framework that provides a direct basis for heritage protection and environmental decision-making. Only by bridging the behavioral understanding and economic estimates can the policymakers design pricing mechanisms, protective incentives and protective communication based on the evidence rather than hypothesis.

In fact, the establishment of an evidence-based assessment does not mean that the price should be raised in a political or social level and the protection fee should be levied immediately. Even if it is not possible to raise ticket prices or collect protection fees at the political or social level, assessment studies can still play a predictive role - that is, it can provide decision-makers with expected evidence of the possible behavioral response under other pricing or management schemes. Therefore, even if they are not implemented in the short term, these models will play a strategic role in facilitating the practical policy shift of such measures in the future.

In order to achieve this goal, we suggest that future research can integrate the design of real hybrid evaluation (combined with CVM, CE and PLS-SEM) into real case studies and policy pilots. These methods will allow researchers to quantify tangible and intangible benefits, discover the behavioral mechanism behind protection support and provide data-supported suggestions for sustainable management. Ultimately, the promotion of evidence-based heritage and environment assessment requires not only the integration of methods, but also a pragmatic commitment to achieving feasible policy results in the combination of academic research and feasible policy results.

## 5. Conclusion

This paper reviews the conceptual and methodological development of three main methods used in non-market valuation-CVM, CE and PLS-SEM-and discusses how the integration of these three methods bridges the economy of human decision-making, Behavioral and cognitive dimensions. Each method provides an unique and complementary perspective: CVM quantifies the monetary threshold of willingness to pay, CE reflects the multi-attribute preference structure, and PLS-SEM reveals the potential psychological mechanism that leads to behavioral intention. They form an integrated whole that connects external valuation and internal motivation.

Through integration, this article highlights the emergence of a unified behavioral valuation perspective in which valuation assessment and psychological interpretation are no longer seen as two independent fields but as two levels that promote each other. This integration enhances theoretical understanding and empirical accuracy so that the valuation research can go beyond static monetary numbers and characterize the dynamic human behavior, cognition and situation.

Although we have made some advances in the methodology, there are still problems to be solved, such as sampling strategy harmonization, harmonizing model assumptions and analytical complexity versus respondents' feasibility. These problems can be solved by designing hybrid questionnaires, multi-level modeling and interdisciplinary cooperation.

Finally, the review stresses that the contribution of these integrated methods is not limited to achieving direct pricing or policy implementation. If direct interventions such as ticket prices adjustments are not feasible, although these models can not be used to gain insights into policy implementation, they can still provide valuable predictions of the public's preferences, behavioral responses and policy outcomes. In this regard, the integration of CVM, CE and PLS-SEM not only benefits academic research, but also enhances the empirical support and provides support for future.

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# Exploration of the Dual-Tutor Mechanism for Graduation Theses in Physics Major

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**Abstract:** Against the backdrop of collaborative talent cultivation and the new college entrance examination reform, the graduation theses of physics normal university students face problems such as the disconnection between theory and practice, and the insufficient connection between students' research capabilities and teaching practice abilities. Combining the interview practice of the dual-tutor mechanism at Tianjiabing Middle School in Ya'an, and taking the Department of Physics of Sichuan Minzu College as an example, this paper analyzes the connotation and value of the dual-tutor mechanism for graduation theses in physics major, sorts out the practical dilemmas such as the low willingness of high school teachers to participate and the difficulty in coordinating tutors' opinions, and proposes optimized paths including hierarchical incentives and collaborative communication. It provides a reference for the talent cultivation of physics major and the coordinated development of basic education.

**Keywords:** Physics; Graduation Thesis; Dual-Tutor Mechanism

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## 1.Introduction

### 1.1 Research Background and Significance

Taking the normal university students of the Department of Physics of Sichuan Minzu College as an example, most of their graduation theses focus on the teaching reform of junior and senior high school physics and the research on question types. However, under the background of collaborative talent cultivation<sup>[1][2]</sup>, through personally guiding and investigating the graduation theses of the 2023 and 2024 graduates of the Department of Physics of Sichuan Minzu College, the author found that most graduation theses have problems such as overly broad topics and the disconnection between theory and practice. At the same time, with the gradual deepening of the new college entrance examination reform, the content that students learn in the three years of senior high school has been reduced. Now, a single question covers more knowledge points, is more comprehensive, and has a stronger ability to distinguish students' levels<sup>[3][4]</sup>. These undoubtedly bring great challenges to senior high school teachers and students, but also provide many new directions for the topic selection of graduation theses of physics normal university students.

### 1.2 Review of Research Status

Fan Zhonghe, in his article "A Brief Discussion on the Writing of Undergraduate Graduation Theses in Physics", pointed

out several common types of topic selection for physics major graduation theses, mainly including teaching content type, teaching method type, teaching experiment type, educational theory type, and applied research type<sup>[5]</sup>. Liu Xuan, in his paper “Practical Exploration on Topic Selection of Graduation Theses in Applied Physics Major”, pointed out that due to the continuous enrollment expansion in recent years, the number of students has been increasing, resulting in a relative shortage of supervisor resources and a relative increase in the number of students guided by each teacher<sup>[6]</sup>. Under such circumstances, it is very necessary to hire off-campus supervisors to assist in guiding students’ graduation theses. Off-campus supervisors should be engineering and technical personnel or researchers with intermediate professional titles or above. In this way, while alleviating the pressure caused by the shortage of supervisors in the physics major, it can also promote the formation of a multi-level structure and a diversified model of the supervisor team<sup>[7]</sup>. At present, many colleges and universities have implemented the dual-tutor system for educational internships. For example, Shanxi Normal University has implemented the system of college teachers being stationed in counties, where college teachers and supervisors from internship schools jointly guide students’ internships, which provides very good conditions for the dual-tutor system for students’ graduation thesis creation<sup>[8]</sup>. Another example is that the chemistry normal major of Jinggangshan University invited some middle school chemistry teaching experts and some professional supervisors for students’ internships to serve as middle school supervisors for students’ graduation theses, established a “dual-tutor” team jointly guided by college teachers and middle school teachers, and implemented the whole-process “dual-tutor” guidance for students’ graduation theses<sup>[9]</sup>.

### 1.3 Research Methods and Objectives

Through methods such as online access to relevant materials, offline reading and guidance of normal university students’ graduation theses, as well as multiple visits to Tianjiabing Middle School in Ya’an City to go deep into the frontline of teaching and internships, and combined with interviews with many teachers from Tianjiabing Middle School and staff of the Ya’an Municipal Bureau of Education, aiming at the many shortcomings in the graduation theses of students in the Department of Physics of Sichuan Minzu College, the author hopes to construct a system in which university teachers and senior high school teachers cooperate to jointly guide the graduation theses of normal university students, and propose solutions to the dilemmas existing in the dual-tutor mechanism, such as differences in teachers’ willingness to participate and difficulties in coordinating tutors’ opinions.

## 2. Connotation and Value of the Dual-Tutor Mechanism for Graduation Theses

Under the background of collaborative talent cultivation, the “dual-tutor system” for the graduation theses of physics normal university students has been endowed with more profound connotation and mission. Collaborative talent cultivation emphasizes breaking down the barriers between colleges and universities and society, integrating multiple resources, and comprehensively cultivating students to become compound talents who meet social needs. The “dual tutors” refer to arranging one college supervisor and one supervisor from the basic education practice base to jointly guide normal university students in the process of completing their graduation theses. Since off-campus tutors have a full understanding of the actual teaching in middle schools, the topic selection of normal university students’ graduation theses can conform to the actual situation of middle school education and teaching under their guidance. From the perspective of the current implementation situation, many colleges and universities have established relatively complete dual-tutor communication and cooperation platforms under the promotion of collaborative talent cultivation projects. Taking the physics major of Sichuan Minzu College as an example, the dual-tutor mechanism for graduation theses takes “collaborative talent cultivation” as the core, clarifies the differentiated division of labor between college tutors and frontline physics teachers in senior high schools, and forms a closed-loop guidance system of “theoretical guidance - practical verification”. The main responsibilities of college tutors lie in grasping the theoretical framework of the thesis and the standardization of formats, such as the citation format of references; the main responsibilities of senior high school teachers lie in guiding students to select topics based on the frontline of teaching, providing practical materials such as teaching cases, real questions from the college entrance examination, and students’ learning feedback, and helping students transform theories into implementable teaching plans. The value of the dual-tutor mechanism for graduation theses is mainly reflected in the realization of a win-

win situation for students, college teachers, and senior high school teachers. For students, the guidance of senior high school teachers can prevent educational theories from being divorced from reality (becoming “empty talk on paper”). Through internship guidance and cooperative discussions, senior high school teachers can provide frontline teaching materials and feedback; the guidance of college teachers can help students construct a theoretical framework, standardize the format of the thesis, and improve their ability to write academic theses. The joint guidance of the two can enable students to achieve the integration of physics knowledge in senior high schools and universities. For college teachers, the guidance of senior high school teachers can not only share part of the heavy thesis guidance pressure of college teachers, but also improve the drawback of colleges and universities attaching importance to theory while neglecting practice through frontline teaching feedback. For senior high school teachers, jointly guiding thesis writing can improve their shortcoming of having rich practical experience but weak ability to organize written content, which is very helpful for the improvement of their research capabilities.

### **3. Practical Dilemmas and Optimized Paths of the Dual-Tutor Mechanism**

#### **3.1 Practical Dilemmas**

##### **(1) Low Willingness of Senior High School Physics Teachers to Participate and Lack of Incentive Mechanism**

From the interview results, senior high school physics teachers generally face objective constraints such as heavy teaching tasks and great pressure from students' further education. Moreover, guiding undergraduate graduation theses is not linked to performance evaluation or professional title promotion. In addition, frontline senior high school teachers have been separated from the undergraduate curriculum teaching and research system for a long time, and many university-level knowledge has been forgotten. Due to these three reasons, the overall willingness of frontline senior high school teachers to participate in guiding the graduation theses of normal university students is relatively low.

##### **(2) Insufficient Coordination of Dual Tutors' Opinions, Easily Leading to Confusion in the Guidance Direction for Students**

College teachers and frontline senior high school teachers may have differences in the guidance of graduation theses. College teachers pay more attention to the integrity of the theoretical framework and may suggest significantly increasing the proportion of the theoretical part; frontline senior high school teachers pay more attention to the practical application value of theories, and they often hope that normal university students can conduct on-site investigations to identify problems, propose feasible solutions, and verify the feasibility of the solutions in subsequent teaching internships.

#### **3.2 Optimized Paths**

##### **(1) Constructing a Hierarchical Incentive Mechanism to Improve the Willingness of Senior High School Physics Teachers to Participate**

First of all, the guidance of senior high school physics teachers to undergraduate graduation theses can be linked to their performance evaluation. Since the School of Mathematics, Physics and Statistics of Sichuan Minzu College has established an internship base in Ya'an and has in-depth cooperation with Tianjiabing Middle School in Ya'an, the college supervisor corresponding to a student's graduation thesis can establish a cooperative relationship with the senior high school supervisor to help the latter improve their academic thesis writing skills, thereby indirectly assisting frontline senior high school teachers in their professional title promotion.

##### **(2) Establishing a Dual-Tutor Collaborative Communication Mechanism to Unify the Guidance Direction**

First of all, it is necessary to establish collaborative guidance rules and clarify the responsibilities of college supervisors and senior high school supervisors in different aspects and parts of the thesis. For example, in the topic selection stage, frontline tutors mainly propose practical directions, and college tutors are responsible for demonstrating the theoretical feasibility; in the first draft stage, college tutors review the format and theoretical logic, and frontline tutors review the authenticity of practical content; in the revision stage, a joint meeting is held to jointly determine the revision plan to avoid opinion conflicts.

### **4. Practical Case**

Taking the graduation thesis of a student in the 2024 physics major- “Research on the Connection between Senior High School Physics and University Physics Knowledge - Taking Thermodynamics as an Example” - as an example. In the topic

selection stage, the student originally tended to choose a topic that did not involve a specific field but focused on the research of the entire physics discipline in senior high school and university. After communication between the college supervisor and the senior high school supervisor, the student was advised to select a narrower, more operable topic that could be combined with practical situations, and the student accepted this suggestion. In the research stage, the college supervisor provided the student with a theoretical framework, such as Piaget's "Cognitive Development Theory" and Vygotsky's "Zone of Proximal Development" theory, to demonstrate the feasibility of the research. The senior high school supervisor analyzed the specific knowledge points of senior high school thermodynamics content, studied the similarities and differences between many knowledge points and university-level content, and put forward some possible connection schemes. In the practical verification stage, with the assistance of the senior high school supervisor, the student carried out exploratory practical teaching during the internship period, guiding senior high school students to think about and discuss some in-depth questions in the classroom, so as to realize the connection between thermodynamics content in senior high school physics and that in university physics. Finally, the university supervisor helped the student revise the thesis format, and finally completed an excellent graduation thesis with prominent practical value and clear theoretical logic.

## Conclusion

Since the graduation theses of physics normal university students often have problems such as the disconnection between theory and practice and the insufficient connection between students' research capabilities and teaching practice abilities, this paper takes the normal university students of the Department of Physics of Sichuan Minzu College as an example, integrates the interviews with Tianjiabing Middle School in Ya'an, and constructs a guidance system of the dual-tutor mechanism for graduation theses based on the actual situation. This system can not only avoid the drawback of normal university students' graduation theses attaching importance to theory while neglecting practice, but also realize a win-win situation for students, college teachers, and senior high school teachers. This scheme can provide a reference for the guidance of graduation theses of normal university students in the Department of Physics in the future.

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## Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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# Theoretical Mechanisms Linking the Digital Economy and Agricultural Economic Resilience: Construction and Analysis Based on a Quantitative Spatial Equilibrium Model

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**Abstract:** This study aimed to construct a Quantitative Spatial Equilibrium (QSE) model that integrates digital factors and agricultural infrastructure, providing a unified theoretical framework for analyzing the underlying mechanisms of agricultural economic resilience. The model embedded a three-dimensional resilience system—resistance–adaptation–transformation—into consumer preferences and production functions. Within the agricultural context, it depicted the generation, exchange, and enabling mechanisms of data as a novel production factor, and elucidated its synergistic interaction pathways with both traditional and digital infrastructures. By incorporating the hat algebra approach, the model enabled counterfactual simulations of policy shocks in multi-regional and multi-sector economic systems, effectively mitigating parameter identification challenges. The theoretical contributions of this research lay in extending the application of quantitative spatial economics to the agricultural domain, identifying the sectoral heterogeneity of data-factor diffusion effects, and providing a formal analytical tool to explore the micro-foundations of how “digital–infrastructure” synergies enhance agricultural economic resilience. These findings established a methodological basis for subsequent empirical investigations and policy evaluations.

**Keywords:** Digital Economy; Agricultural Economic Resilience; Quantitative Spatial Equilibrium (QSE) Model; Data as a Production Factor; Digital–Infrastructure Synergy

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## 1.Introduction

The deep integration of the digital economy and agricultural modernization has been reshaping agricultural production methods and rural economic structures, injecting new momentum into enhancing agricultural resilience and sustainable development. According to the 2023 Report of the Ministry of Agriculture and Rural Affairs, the informatization rate of agricultural production in China had exceeded 25%, and the scale of the agricultural digital economy had reached 2.8 trillion yuan, demonstrating a remarkable annual growth rate<sup>[1,2]</sup>. Against this backdrop, digital technologies empowered agricultural production, distribution, services, and consumption, thereby significantly strengthening the resilience of the agricultural economic system<sup>[3]</sup>. At the policy level, since 2022, successive No.1 Central Policy Documents have emphasized the promotion of digital villages and the digital transformation of the entire agricultural value chain, aiming to systematically enhance agricultural economic resilience and sustainability. Theoretically, the digital economy—with its pervasive,



synergistic, and inclusive characteristics—has laid the micro-foundation for improving agricultural resilience<sup>[4,5]</sup>. Data, as a critical new production factor, optimized agricultural resource allocation, improved total factor productivity, and strengthened the system's capacity for shock resistance and adaptive response through information integration and intelligent decision-making<sup>[6,7]</sup>. Meanwhile, agricultural infrastructure—particularly digitalized facilities such as information networks and cold-chain logistics—served as essential physical carriers for digital empowerment. According to quantitative spatial economics, infrastructure played a central role in enhancing adaptability and recoverability by reducing factor mobility costs, improving spatial allocation efficiency, and strengthening regional connectivity<sup>[8,9]</sup>.

However, existing research primarily focused on empirical verification and lacked a unified theoretical framework that integrated digital factors, infrastructure, and resilience. In particular, few studies clearly characterized the unique economic attributes of data factors and their synergistic mechanisms with infrastructure<sup>[10]</sup>. To fill this theoretical gap, this study constructed a Quantitative Spatial Equilibrium (QSE) model incorporating digital factors and agricultural infrastructure, aiming to formally analyze the formation mechanisms of agricultural economic resilience from the three dimensions of resistance–adaptation–transformation.

The theoretical contributions of this study were threefold. First, it explicitly incorporated data factors into the agricultural production function, defining their non-rivalry nature and dynamic accumulation process. Second, it calibrated infrastructure elasticity within a structural model to support counterfactual simulations. Third, it uncovered three core mechanism pathways—technological progress, resource allocation, and institutional adaptation—thus providing a robust theoretical foundation for enhancing agricultural resilience and promoting high-quality development through coordinated “digital–infrastructure–institutional” policies.

## **2. Empirical Characteristics of Agricultural Economic Resilience and Digital Economy Development in China**

To provide an empirical foundation for the theoretical model, this section briefly outlines and analyzes the key characteristics of China's agricultural digitalization and economic resilience.

### **2.1 Regional Concentration and Structural Imbalance of Agricultural Digital Talent**

Agricultural digital talent serves as the core carrier for the application of digital technologies. Following the classification proposed by Sun Jiulin et al.<sup>[11]</sup>, this study defined such talent as rural employees engaged in occupations related to digital technology application, agricultural data analysis, and the operation of intelligent agricultural machinery. The analysis revealed that between 2014 and 2024, the overall proportion of agricultural digital talent in China increased steadily, yet the regional distribution remained highly uneven. The share in eastern regions rose rapidly from 3.8% to 9.2%, significantly ahead of the central (5.6%) and western (3.4%) regions. Although grain-producing regions exhibited a higher proportion of digital talent than non-grain regions, their growth rate was relatively modest. This pronounced regional imbalance reflected substantial differences in the depth of digital technology adoption in agriculture and suggested the emergence of a “digital dividend divide,” a phenomenon consistent with patterns of skill-biased technological change observed in other developing economies<sup>[12]</sup>. Consequently, it underscored the necessity of incorporating regional heterogeneity into the theoretical model.

### **2.2 Pronounced Spatial Disparities in Digital Infrastructure Development**

Digital infrastructure constitutes the fundamental prerequisite for the functioning of digital factors. Based on a composite index constructed from indicators such as rural broadband access rates and 5G base station coverage, the national average value of China's digital infrastructure index reached only 0.52 in 2024, with striking regional disparities—0.78 in the east, 0.51 in the center, and 0.32 in the west. Notably, the spatial distribution of this index exhibited a strong positive correlation ( $r = 0.83$ ) with the agricultural economic resilience index, and the regional gap had widened since 2018. This pattern of infrastructure divergence and its economic consequences aligns with findings on the digital divide in other contexts<sup>[13]</sup>.

The eastern region experienced rapid improvement, driven by “digital village” pilot policies, while the western region lagged behind due to natural and economic constraints. This sharp contrast in baseline conditions represents a critical exogenous constraint that must be accounted for in constructing a multi-regional spatial equilibrium model.

## 2.3 Efficiency and Structural Issues in Agricultural Infrastructure Investment

Although total investment in agricultural infrastructure continued to grow, its efficiency exhibited a downward trend. The increase in total factor productivity (TFP) per unit of investment declined from 0.32 in 2014 to 0.18 in 2024. Meanwhile, structural imbalances in investment allocation became evident: the return elasticity of investment in rural road transport and storage logistics facilities was relatively high (0.24 and 0.21, respectively), whereas that of traditional irrigation facilities remained low (only 0.07). This underscores the importance of not just the volume but the type of infrastructure investment, a factor critical for growth and resilience<sup>[14]</sup>.

This pattern revealed both the urgency of upgrading traditional infrastructure and the crucial role of digital transformation in enhancing investment efficiency. It also implied that the type of infrastructure and the degree of its digitalization were key determinants of its enabling efficiency. These findings provided a strong empirical rationale for distinguishing between traditional and digital infrastructures in the theoretical model and for analyzing their complementary relationship, particularly in building adaptive capacity to climate shocks<sup>[15]</sup>.

## 3. Model Specification

This study constructed a multi-regional monopolistic competition general equilibrium model within the theoretical framework of Quantitative Spatial Economics (QSE). The model incorporated digital factor inputs, agricultural infrastructure, and intersectoral production linkages, building on foundational spatial equilibrium theories<sup>[16]</sup>. It aimed to characterize an economic system consisting of  $N$  regions, each containing an agricultural sector—further disaggregated into grain production ( $a_1$ ), cash crops ( $a_2$ ), and livestock & fisheries ( $a_3$ )—a local non-agricultural services sector ( $s$ ), and an external market.

The model featured three core innovations. First, it embedded the multidimensional “resistance–adaptation–transformation” framework of agricultural economic resilience into both consumer preferences and production functions, reflecting a growing emphasis on resilience in economic modeling<sup>[17]</sup>. Second, it explicitly modeled the generation, trading, and enabling mechanisms of agricultural data factors, while distinguishing between the dual roles of traditional and digital infrastructure. Third, it accounted for factor mobility and technological spillovers both within the agricultural sector and between agricultural and non-agricultural sectors, thereby enabling a more comprehensive simulation of the spatial general equilibrium effects of policy shocks<sup>[18]</sup>.

### 3.1 Generation and Accumulation of Agricultural Data Factors

This paper treated data as an accumulable and essential production factor, recognizing its unique economic properties<sup>[19]</sup>. In region  $i$  and period  $t$ , the data stock of the agricultural sector (representative subindustry  $g$ ), denoted as  $D_{it}$ , comprised two components: self-collected data ( $D^{\text{coll}}_{it}$ ), generated automatically during agricultural operations via IoT devices and e-commerce platforms; and externally purchased data ( $D^{\text{buy}}_{it}$ ) acquired from data markets.

Data, characterized by non-rivalry and replicability, followed the dynamic accumulation process. The amount of data collected ( $D^{\text{coll}}_{it}$ ) was positively related to the level of digital technology ( $A_{it}$ ) and the scale of agricultural activities ( $X_{k,it}$ ). Government agencies or enterprises could purchase external data at price  $p_{\text{buy},it}$  in data markets. The non-rival nature of data allowed its simultaneous use in local production (e.g., precision fertilization) and interregional trade.

### 3.2 Consumer Preferences and Resilience Evaluation System

Agricultural economic resilience was incorporated into the consumer utility function to capture preferences for system stability and sustainability. Following recent advances in welfare measurement under uncertainty<sup>[20]</sup>, the resilience index of region  $i$  in period  $t$  ( $R_{it}$ ) was defined as a composite CES function of three dimensions: resistance ( $R_{\text{res},it}$ ), adaptation ( $R_{\text{adj},it}$ ), and transformation ( $R_{\text{inno},it}$ ). The final utility of consumers depended on agricultural product consumption ( $C_{it}$ ) and resilience level ( $R_{it}$ ).

### 3.3 Production Function and Data-Driven Enabling Mechanism

Agricultural production followed a nested CES–Cobb–Douglas structure, integrating data factors as a new input alongside traditional factors such as labor and capital. The representative firm in sector  $g$  of region  $i$  produced output accordingly. The parameter  $\delta$  captured the data-driven enabling effect: a higher  $\delta$  indicated a stronger enhancement of productivity through digital technologies, thereby improving the system’s capacity to withstand external shocks, a mechanism increasingly

documented in the literature on technology and productivity (18).

### 3.4 Composite Mechanism of Agricultural Infrastructure

Agricultural infrastructure (Git) was modeled as a composite form comprising traditional infrastructure (Gtra,it), such as irrigation, transport, and storage, and digital infrastructure (Gdig,it), such as 5G networks and IoT systems. These components were combined through a CES function. Infrastructure influenced agricultural economic resilience through multiple channels, including reducing transportation costs, enhancing information transparency, and optimizing resource allocation<sup>[21]</sup>. The transportation cost for agricultural goods between regions *i* and *j* ( $\tau_{ijt}$ ) was assumed to be inversely related to the infrastructure level.

### 3.5 Factor Mobility and Policy Intervention

Rural labor was assumed to be mobile across agricultural and non-agricultural sectors as well as across regions. Migration decisions depended on expected utility differentials and migration costs, consistent with spatial equilibrium models<sup>[22]</sup>. Government intervention influenced agricultural resilience through taxation, subsidies, and infrastructure investment.

### 3.6 Equilibrium Conditions and Resilience Feedback Mechanism

The model achieved closure through the simultaneous clearing of product, labor, data, and infrastructure markets. Agricultural economic resilience (Rit) was not treated as exogenous; instead, it dynamically influenced production efficiency, investment performance, and consumer confidence, forming a positive feedback loop, a feature central to understanding path-dependent development outcomes<sup>[23]</sup>. By calibrating provincial-level parameters for China and conducting counterfactual simulations, the model quantitatively evaluated the contributions and transmission mechanisms of the digital economy and infrastructure to agricultural economic resilience.

## 4. Theoretical Analysis

To elucidate the underlying mechanisms through which the digital economy and agricultural infrastructure influence agricultural economic resilience, this study adopted the “Hat Algebra” approach proposed by Dekle et al. to transform the above general equilibrium model into a system expressed in relative changes<sup>[24]</sup>. Let the observed variable be  $x$ , and its counterfactual value be  $x'$ ; then, the relative change is defined as  $\hat{x} = x'/x$ . By taking this differential form, the method effectively eliminates constant parameters, highlights the structural variations induced by policy shocks, and reduces the number of parameters requiring estimation, thereby improving model identification. Within this framework, this section theoretically derives the core mechanisms through which digital factors and infrastructure affect agricultural economic resilience.

### 4.1 Impact of the Digital Economy on Agricultural Total Factor Productivity

Starting from the producer’s equilibrium condition and based on the production function described above, the relative change in agricultural Total Factor Productivity (TFP) primarily depends on the relative change in data input and its output elasticity:

$$\widehat{TFP}_{it} \propto \hat{D}_{it}^{\delta} \quad (11)$$

Since the output elasticity of data input ( $\delta > 0$ ) was positive, agricultural TFP responded positively to the increase in data factor investment. This indicated that the application of digital technologies became a key pathway for improving agricultural TFP by optimizing decision-making, enabling precision input, and reducing production volatility<sup>[25]</sup>. The non-rivalrous nature of data further amplifies these productivity effects across different agricultural applications<sup>[1,26]</sup>.

### 4.2 Impact of Digital Infrastructure on the Three Dimensions of Agricultural Resilience

The relative change in the three-dimensional capacities of agricultural resilience can be expressed as a function of the relative change in the stock of digital infrastructure:

$$\hat{R}_{res} = \eta_{res} \cdot \hat{G}_{dig}, \quad \hat{R}_{adj} = \eta_{adj} \cdot \hat{G}_{dig}, \quad \hat{R}_{inno} = \eta_{inno} \cdot \hat{G}_{dig} \quad (11)$$

where  $\eta_{res}$ ,  $\eta_{adj}$ ,  $\eta_{inno}$  (all  $> 0$ ) denote the elasticities of digital infrastructure with respect to resistance, adaptation, and transformation capacities, respectively.

This demonstrated that digital infrastructure enhanced agricultural economic resilience through three pathways: improving information accessibility, reducing transaction costs, and promoting technological innovation<sup>[21]</sup>. Theoretically, the elasticity coefficient for innovation and transformation ( $\eta_{inno}$ ) was typically the largest, implying that digital infrastructure was

particularly effective in driving long-term structural transformation by enabling new business models and facilitating knowledge spillovers across the agricultural value chain<sup>[23,27]</sup>.

### 4.3 Synergistic Mechanism between Agricultural Infrastructure and Resilience Enhancement

Traditional and digital infrastructures exhibited a complementary relationship. The marginal contribution of composite infrastructure stock to agricultural output could be decomposed as follows:

$$\frac{\partial \hat{Y}_{ig}}{\partial \hat{G}_{it}} = \underbrace{\frac{\partial \hat{Y}_{ig}}{\partial \hat{G}_{it}}}_{\text{Direct effect}} + \underbrace{\frac{\partial \hat{Y}_{ig}}{\partial \hat{R}_{it}} \cdot \frac{\partial \hat{R}_{it}}{\partial \hat{G}_{it}}}_{\text{Indirect toughness effect}} \quad (12)$$

This indicated that infrastructure not only directly promoted agricultural growth but also indirectly enhanced output stability and sustainability by strengthening economic resilience<sup>[28,29]</sup>. The synergistic effect depended on the elasticity of substitution ( $\rho$ ) and the composite weight ( $\pi$ ) between traditional and digital infrastructures. Such complementarity is particularly crucial in developing country contexts where infrastructure gaps persist<sup>[21]</sup>.

### 4.4 Heterogeneous Effects under Different Scenarios

The theoretical model suggested significant sectoral and regional heterogeneity in the effects of the digital economy and infrastructure on resilience. For instance:

Major grain-producing regions: Given the relatively high stock of traditional infrastructure, marginal improvements in digital infrastructure exerted a stronger influence on adaptive capacity (Radj), as digitalization more effectively optimized the allocation efficiency of existing resources<sup>[22]</sup>.

Economically developed regions: Digital infrastructure had a more pronounced effect on innovative and transformative capacity (Rinno), as these regions possessed more mature market ecosystems and stronger innovation capabilities to absorb and convert disruptive digital technologies<sup>[13]</sup>.

This heterogeneity warranted close examination in subsequent counterfactual simulations.

### 4.5 Integrated Effects of Multidimensional Resilience on Agricultural Growth

Agricultural economic resilience affected agricultural value added through three channels—stabilizing production, optimizing resource allocation, and promoting innovation. The relative change in total output could be decomposed into changes in factor inputs and TFP variations induced by resilience:

$$\hat{Y}_{ig} \approx \hat{L}_{ig}^{\beta} \cdot \hat{K}_{ig}^{\gamma} \cdot \hat{D}_{it}^{\delta} \cdot \hat{R}_{it}^{\zeta} \quad (13)$$

where  $\zeta$  denoted the elasticity of resilience with respect to output. This indicated that improvements in agricultural economic resilience independently contributed to agricultural output growth. Particularly under external shocks, resilience helped maintain system stability and mitigate output volatility<sup>[17]</sup>. This theoretically demonstrated the long-term value of investing in resilience-building, especially in the context of increasing climate variability and market disruptions<sup>[3]</sup>.

## 5. Quantitative Methodology and Parameter Calibration

The theoretical model developed in this study was ultimately applied to real-world economic analysis through quantitative implementation. The key analytical strength of the model lay in its capacity for calibration and counterfactual simulation. This section elaborates on the quantitative realization strategy and the calibration procedures for the core structural parameters.

### 5.1 Counterfactual Simulation Based on the Hat Algebra Method

To effectively assess the impacts of policy shocks, this study adopted the Hat Algebra approach proposed by Dekle et al.<sup>[24]</sup>, transforming the multi-sector general equilibrium framework into a computable system of equations expressed in relative changes, defined as  $\hat{x} = x'/x$ . The advantages of this approach were threefold:

Avoidance of over-parameterization — it did not require full calibration of deeply unobservable structural parameters such as absolute productivity levels;

Data-driven structure — it directly utilized empirically observed baseline equilibrium data such as trade flows and factor shares;

Shock tracing capability — it allowed direct computation of the relative changes in endogenous variables resulting from

exogenous shocks, such as increases in digital infrastructure investment.

$$\{\pi_{ait}, \Psi_{ait}, \varpi_{ait}, L_{ait}, w_{ait}, Y_{ait}, G_{dig,it}, G_{tra,it}\}$$

Given a set of baseline observations and the exogenous specification of:

digital infrastructure investment shocks,

changes in agricultural data-factor inputs, and external market variations<sup>[31]</sup>, the model solved for the endogenous system of relative changes under a pre-specified set of deep structural parameters.

$$\{\delta, \beta, \gamma, \rho, \sigma, \theta, \kappa, \eta_{res}, \eta_{adj}, \eta_{inno}\}$$

$$[\hat{w}_{ait}, \hat{L}_{ait}, \hat{\pi}_{ait}, \hat{R}_{res,it}, \hat{R}_{adj,it}, \hat{R}_{inno,it}, \hat{Y}_{ait}]$$

This approach accurately captured the dynamic responses of the agricultural economic system to digital technology shocks and effectively mitigated systemic bias arising from structural economic changes.

## 5.2 Parameter Calibration Strategy

To enable numerical simulation, the model's structural parameters required careful calibration. This study employed a hybrid approach combining structural estimation and literature-constrained calibration.

### (1) Literature-Constrained Parameters

Several key parameters were directly drawn from established studies and adjusted to reflect the characteristics of China's agricultural economy:

Output elasticity of data factors ( $\delta$ : 0.08–0.12<sup>[1,8,32]</sup>,

Elasticities of digital infrastructure with respect to the three resilience dimensions:

$$\eta_{res} \in [0.05, 0.15]$$

$$\eta_{adj} \in [0.06, 0.18]$$

$$\eta_{inno} \in [0.10, 0.25]^{[21,33]},$$

Output elasticity of traditional agricultural infrastructure ( $\xi$ : 0.12<sup>[28]</sup>,

Labor output elasticity ( $\beta$ ): 0.28 (reference value from related empirical research<sup>[34,35]</sup>,

Intermediate input elasticity ( $\gamma$ ): determined from the structure of regional input–output tables<sup>[36]</sup>.

### (2) Fitted Parameters

The remaining parameters were obtained through a residual-minimization fitting process, formulated as the following optimization problem:

$$\min_{\theta_k} \sum_i \sum_t [Y_{it}^{model}(\theta_k) - Y_{it}^{data}]^2 + \lambda_k \sum_k (\theta_k - \bar{\theta}_k)^2 \quad (14)$$

where

$Y_{it}^{model}$ : model represents the model-predicted agricultural output,

$Y_{it}^{data}$ : the observed output,

$\theta_k$ : the vector of estimated parameters,

$\lambda_k$ : the constraint weight, and

$\bar{\theta}_k$ : the reference values derived from prior literature.

This calibration procedure ensured that the model could reproduce the observed evolution of agricultural economic resilience in China while maintaining parameter consistency with economic theory, thereby providing a reliable baseline for counterfactual analysis.

## 5.3 Stock Computation and Data Processing

The agricultural data-factor stock ( $D_{it}$ ) was computed using the perpetual inventory method (PIM). The initial stock was estimated based on agricultural data-resource surveys, while the depreciation rate followed the benchmark for ICT capital, set at 15%<sup>[37]</sup>. Similarly, both digital and traditional infrastructure stocks were constructed using investment series and corresponding depreciation rates under the perpetual inventory framework.

## 5.4 Summary

Through the hybrid calibration strategy that integrated literature constraints and fitted estimation, this study ensured both the



economic plausibility and empirical relevance of the parameterization. Consequently, the theoretical model evolved into a quantitative analytical tool capable of conducting policy experiments and counterfactual evaluations tailored to the realities of China's agricultural economy.

## 6. Conclusion and Policy Implications

This study developed a Quantitative Spatial Equilibrium (QSE) model that integrated digital factors and agricultural infrastructure to provide a unified analytical framework for understanding the formation mechanism of agricultural economic resilience along three dimensions—resistance, adaptation, and transformation. The theoretical contribution lay in explicitly incorporating data factors as a non-rival and novel production input into the production function and formally characterizing their synergistic interaction with both traditional and digital infrastructures<sup>[19,21]</sup>. This approach revealed the intrinsic logic of “digital empowerment–infrastructure support–resilience enhancement.”

### 6.1 Main Findings

#### 1) Applicability of the Theoretical Framework

This study extended the application of Quantitative Spatial Economics (QSE) to the agricultural domain. The constructed model effectively captured multi-regional, multi-sectoral, and multi-factor interactions, providing a formalized analytical tool for exploring spatial equilibrium and resilience responses within the agricultural economic system<sup>[16]</sup>.

#### 2) Core Mechanism of Data Factors

The theoretical derivation demonstrated that data factors directly enhanced agricultural economic resilience by increasing total factor productivity (TFP). Their non-rivalry and cumulative characteristics implied decreasing marginal costs and additive efficiency effects, forming the microeconomic foundation for their role as a primary driver of resilience enhancement<sup>[19]</sup>.

#### 3) Synergistic Amplification Effects of Infrastructure

The model revealed that infrastructure contributed to agricultural performance through both direct and indirect channels—it reduced transaction and logistics costs while simultaneously amplifying economic resilience<sup>[9]</sup>. The relationship between traditional and digital infrastructure was complementary rather than substitutive, governed by the elasticity of substitution ( $\rho$ ). Their effective integration emerged as the key to maximizing resilience improvement.

4) Theoretical Significance of Heterogeneity

The model's endogenous regional and sectoral heterogeneity indicated that identical policy shocks—such as increased investment in digital infrastructure—generated heterogeneous impacts across regions and industries. This theoretical finding underscored the limitations of “one-size-fits-all” policy approaches and highlighted the necessity of tailoring policies to local factor endowments and economic structures (Bryan & Morten, 2019).

### 6.2 Theoretical Insights and Policy Implications

#### 1) Treating Data-Factor Accumulation as a Long-Term Strategy

Policymakers should move beyond perceiving digital technologies merely as instrumental tools and instead treat them as core production factors requiring systematic development. This entails establishing an agricultural data resource system that is well-defined in ownership, open and shareable, and securely managed, thereby laying the institutional foundation for data accumulation and market-based exchange<sup>[5]</sup>.

#### 2) Strengthening Synergistic Investment between Digital and Physical Infrastructure

The findings suggested that the enabling effect of digital technologies critically depended on the modernization of traditional infrastructure. Policies should promote integrated infrastructure investment, such as embedding IoT sensors during the construction of high-standard farmland or integrating smart logistics networks when upgrading rural transportation systems, to maximize synergistic investment effects<sup>[38]</sup>.

#### 3) Designing Policies According to the Heterogeneity of Resilience Dimensions

The theoretical model indicated that digital technologies exerted the strongest influence on transformational capacity, while their impact on resistance capacity was comparatively limited. Consequently, in regions vulnerable to natural shocks, policymakers should not rely solely on digital technologies but complement them with hard infrastructure such as water

conservancy and disaster prevention facilities, forming a combined approach of “digital early warning + engineering defense”<sup>[10]</sup>.

#### 4) Providing a Quantitative Tool for Policy Evaluation

The proposed quantitative spatial equilibrium model, coupled with the Hat Algebra approach<sup>[24]</sup>, offered a scalable analytical framework and quantitative tool for assessing the macroeconomic and spatial spillover effects of digital agriculture policies, including subsidies, pilot programs, and infrastructure investments.

### 6.3 Summary

In summary, this study provided theoretical evidence for the feasibility and significance of the synergistic interaction between the digital economy and agricultural infrastructure in enhancing agricultural economic resilience. Future research could extend this framework through empirical estimation and counterfactual simulations using more granular datasets, thereby offering more precise policy insights to promote high-quality agricultural development and advance the goal of building a strong agricultural nation.

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# Employee Relationship Management in Resorts under Artificial Intelligence: A Systematic Literature Review and Research Agenda

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**Abstract:** As managers increasingly seek to apply artificial intelligence (AI) technologies to optimize operations and shape competitive advantage, research on the impact of AI on employees within the hospitality and tourism industry has grown in recent years. Despite the importance of this topic, systematic studies of employee relationship management in the resort context remain limited and fragmented. This study employs a systematic literature review to examine 36 English-language academic publications released between 2015 and 2024. It proposes a definition and conceptual framework for employee relationship management in the AI era, suited to resort settings. The framework outlines key antecedents, outcomes, mediating, and moderating variables in this field. The findings not only present the current state of research but also identify existing gaps, offering directions for future investigation. In addition, the analysis provides theoretical grounding and practical insights for resort managers aiming to manage employee relations effectively and enhance organizational performance in the age of artificial intelligence.

**Keywords:** Artificial Intelligence; Employee Relationship Management; Resorts; Systematic Literature Review; Research Agenda

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## 1.Introduction

This study aims to identify the current state and emerging directions of research on employee relations in resort settings within the context of artificial intelligence, through a systematic literature review. Building on this foundation, it proposes an integrated framework with practical implications. To ensure methodological transparency and replicability, the study follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement<sup>[1]</sup>. Peer-reviewed English-language journal articles were systematically searched, screened, and assessed. The databases, search strategies, time frame, and inclusion and exclusion criteria are described in detail in the methodology section.

In the global tourism industry, resorts represent a premium segment that serves as both a key pillar of the leisure economy and a central vehicle for delivering service quality and experiential value. Unlike traditional models that rely on standardized tangible products, the core value of a resort lies in its ability to offer highly customized and emotionally engaging experiences. This characteristic underscores a deep dependence on human involvement, encompassing not only frontline employees who interact directly with guests but also, increasingly, artificial intelligence as a technological enabler<sup>[2]</sup>.

The high-contact and experience-driven nature of resort operations makes a stable, engaged, and adaptable workforce, capable of collaborating within emerging human–machine environments, a strategic resource. Artificial intelligence has been adopted across the hospitality industry for its operational efficiency and functional benefits<sup>[3]</sup>. However, resorts continue to face structural challenges such as seasonal employment patterns and the intensive emotional demands of service work<sup>[4]</sup>. While the introduction of AI offers opportunities to enhance operational efficiency and reduce routine workloads, its implementation can also become a double-edged instrument in practice. Poorly managed deployment may heighten employees’ perceptions of job insecurity and lead to emotional exhaustion or turnover intentions<sup>[5]</sup>, thereby eroding the very human capital on which resort competitiveness depends.

Within this context, the question of how to foster constructive employee relations that promote human–machine collaboration rather than opposition has become increasingly salient. For resorts, this issue extends beyond workforce management; it is closely tied to the consistency of service delivery, organizational resilience, and long-term competitive sustainability.

Existing research remains limited in several respects. Most studies emphasize the direct effect of AI awareness on a single outcome variable or examine the role of specific moderating factors. Few have developed an integrated framework situated in the context of resorts that systematically explains the complex interactions among AI integration, employees’ psychological perceptions, and key employee relationship practices. This gap constrains our understanding of how AI influences essential employee attitudes and behaviors through the mediating mechanisms embedded in employee relations.

Although resorts may imitate compensation structures, business processes, or even the adoption of AI technologies, the relational foundations shaped during technological transformation—particularly those centered on perceived organizational support and interactional fairness—are not easily replicated<sup>[6]</sup>. Within the context of AI integration, achieving a distinctive and sustainable competitive advantage requires moving beyond a focus on technology itself. It involves clarifying how employees’ perceptions of AI interact with relational dimensions to shape their attitudes and behaviors.

By systematically synthesizing and reviewing existing studies, this research seeks to advance understanding in this field and provide a conceptual foundation for future theoretical inquiry and managerial application. The research problems addressed in this study are summarized in Table 1.

*Table 1 Research Problems*

number	Research Problems
RQ1	In the context of resort AI integration, how is “employee relations” defined?
RQ2	What are the key dimensions of employee relations in resorts with AI integration?
RQ3	What are the antecedent and outcome variables of employee relations in resorts with AI integration?
RQ4	Which variables moderate or mediate the relationship between AI integration and resort employee relationship outcomes?

## 2.Scope and Conceptualization

Although positive employee relations are essential for resorts to maintain service consistency, build customer reputation, and strengthen organizational resilience in competitive environments<sup>[7]</sup>, academic attention to this topic remains limited and fragmented. Existing studies often draw on concepts from organizational behavior, such as perceived organizational support, organizational justice<sup>[8]</sup>, psychological safety<sup>[9]</sup>, and leadership styles<sup>[10]</sup>. However, there is a lack of systematic inquiry that treats “employee relations in resorts under AI-driven work conditions” as an integrated and operational construct. This theoretical fragmentation leaves management practice without a coherent framework for diagnosing, designing, and evaluating interventions aimed at fostering constructive employee relations.

To ensure conceptual comparability and practical relevance, this study focuses on formal employment relationships within resort organizations. The scope includes full-time and seasonal employees working in resorts where accommodation serves as the core business, integrated with food and beverage, leisure, and entertainment services. Studies on “resort hotels” with high comparability are also considered when relevant. Scenarios related to peer-to-peer or sharing economy platforms, as well as platform-based gig work, are excluded due to their distinct relational foundations, institutional arrangements, and risk–

risk-responsibility structures, which differ substantially from those in traditional resort employment relations.

In the literature, the concept of employee relations often overlaps with several related constructs, such as the employee-organization relationship, psychological contract, employee relations climate, and perceived organizational support. Although these terms differ in labeling, they converge on a shared core idea: employees' overall perception of fairness, respect, communication, and psychological safety within the organization.

Measurement approaches to employee relations vary across studies. Some adopt general scales, such as those assessing perceived organizational support, organizational justice, or psychological safety, emphasizing overall experiences. Others employ more diagnostic instruments, including measures of interactional justice, employee voice, or abusive supervision, which capture the mechanisms through which specific managerial practices operate. This diversity has led to conceptual and dimensional inconsistencies in defining employee relations within resort research, leaving the construct both complex and lacking in consensus.

In summary, early studies on employee relations originated from the perspectives of social exchange and organizational justice<sup>[11]</sup>. As theoretical development progressed, scholars incorporated frameworks such as social identity theory and conservation of resources theory, thereby extending the explanatory scope of the field. Despite these advances, research in the context of resorts still lacks a systematic review that traces the evolution of the employee relations construct and its measurement, and that evaluates the applicability of general versus diagnostic indicators. Moreover, how the distinctive contextual features of the resort industry, such as seasonal employment, residential work arrangements, and the high degree of interdepartmental collaboration, interact with AI technologies to shape both the formation process and outcomes of employee relations remains insufficiently explored. Conducting a structured, industry-specific review is therefore necessary to determine whether existing methodological approaches adequately support the refinement of management practices in resort organizations.

### 3. Methodology

This study adopts a systematic literature review to integrate the knowledge framework of employee relationship management in resorts within AI-enabled work environments. The purpose of a systematic review is to consolidate knowledge in a specific domain, to draw upon the most recent advances, to avoid research that adds little substantive value to disciplinary development, and to provide an evidence-based foundation for claims of novelty by comparing existing and emerging insights<sup>[12]</sup>.

The process involves defining research questions, collecting, preparing, and analyzing data, and reporting the results<sup>[13]</sup>. The procedures used for study selection follow the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. PRISMA is widely recognized within the academic community as a standard for reporting systematic reviews<sup>[14]</sup>. Compared with purely bibliometric or thematic reviews, this approach enhances transparency in the selection and analysis of literature, providing a clear reference point for subsequent studies and distinguishing the present research from prior work in related areas.

As shown in Figure 1, the review process comprises four stages: identification, screening, eligibility assessment, and inclusion.

To comprehensively identify relevant literature, the initial screening focused on English-language journal articles without setting a publication year limit. This approach aimed to capture the earliest studies addressing the topic within the resort context. The primary databases used were Scopus and Web of Science. To reflect the varied expressions and subfields of "employee relations" in management and tourism/hospitality research, multiple sets of synonymous and related constructs were included in the search strategy, emphasizing the intersection between resort operations and the application of AI technologies.

"employee relations" AND resort

"organizational justice" AND ("resort" OR "resort hotel")

"employee voice" OR "change communication"

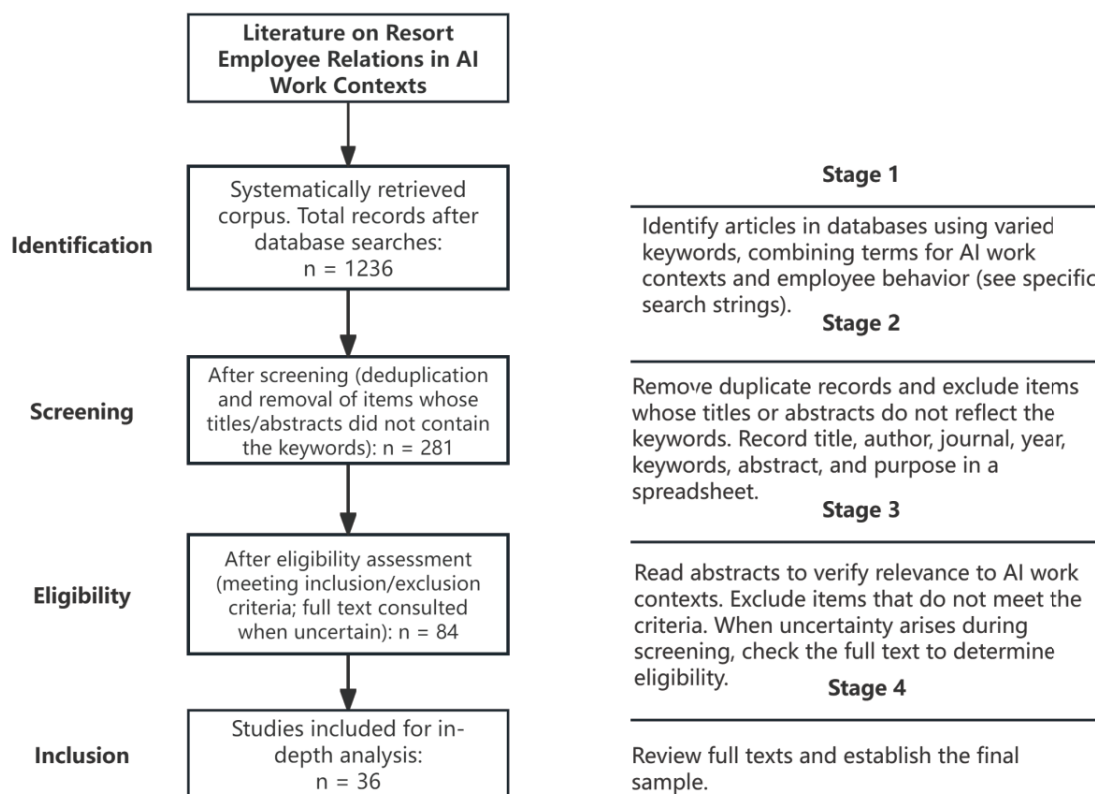
AND "integrated resort" OR "all-inclusive"

"abusive supervision" OR "workplace harassment" AND resort

"artificial intelligence" "robot" OR "automation" AND "employee" OR "staff"

The retrieved records were imported into the reference management software Zotero for cross-database deduplication. An accompanying spreadsheet was used to document key information, including title, author, journal, year, abstract, research objective, context, methodology, and main variables, to facilitate subsequent screening and coding. The screening process substantially reduced the number of studies for analysis: of the 1,236 initially identified records, only 281 proceeded to the third stage.

Figure 1 Research selection process



The core task of the screening stage was to exclude studies that did not meet the inclusion and exclusion criteria. During this process, researchers carefully examined the abstracts of all retrieved records. When uncertainty arose, full texts were reviewed to determine eligibility for inclusion in the final analysis. To ensure the quality and consistency of the literature selection, explicit inclusion and exclusion criteria were established.

Eligible studies were required to meet the following criteria: they had to be journal articles published in English, appear in peer-reviewed journals, and focus directly on employee relationship management or related constructs in AI-enabled resort contexts. In addition, the title or abstract had to contain the predefined search keywords. Articles were excluded under any of the following conditions: the study did not concern resorts or could not be clearly mapped to resort settings; it focused on human–platform relationships within the sharing or gig economy; or it addressed labor relations and trade union issues at a purely macro level without applicability to organizational or unit-level practices.

After the eligibility screening was completed, all articles were organized into a dedicated Zotero folder, and duplicate records were removed. The research team maintained an electronic spreadsheet to track the list of preliminarily screened studies and conducted a full reading of all articles before finalizing the selection. Following the exclusion of studies that did not meet the criteria, the number of papers was reduced from 84 to 36. The inclusion stage referred to the final set of articles incorporated into the sample for quantitative analysis<sup>[15]</sup>. The final sample comprised 36 studies for further examination. Each article was read in full, and all relevant information was systematically recorded in an Excel sheet. As the final verification step, the research team implemented a cross-checking procedure to ensure the representativeness of the selected studies. In this process, researchers independently extracted key information from each article. After jointly reviewing a subset of the materials, the team reached consensus on data extraction standards and maintained close communication throughout, particularly when



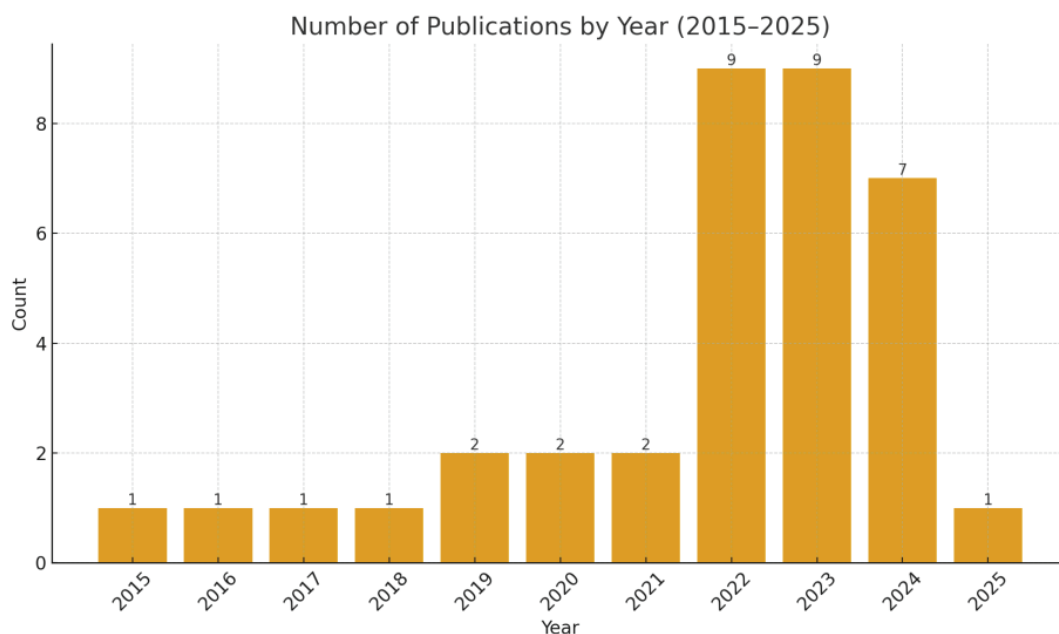
clarification was required for specific cases. Upon completion of this stage, two international scholars specializing in human resource management were consulted. These experts had participated in validating the inclusion criteria at earlier stages and subsequently reviewed and confirmed the final sample of selected studies.

## 4. Analysis and results

### 4.1 Publications by year

Figure 2 illustrates the annual distribution of studies related to artificial intelligence (AI) and employees in the hospitality industry from 2000 to 2025. No publication year limits were applied during the search process, and the earliest identified study on this topic dates back to 2015. The number of publications remained limited in the subsequent years. Research activity began to increase from 2017 onward and reached its peak in 2022 ( $n = 9$ ), followed by 2023 ( $n = 9$ ). These results indicate that the topic of AI and employees in the hospitality sector has gained more focused attention in recent years. Within the sample analyzed in this review, studies published between 2020 and 2025 account for approximately 83% (30 out of 36).

*Figure 2 Articles published per year*



### 4.2 Publications by journal and research methodology

Table 2 presents the distribution of publications across journals. Overall, the number of studies is relatively balanced, with most journals publishing one or two articles each. In terms of publication volume, the International Journal of Contemporary Hospitality Management (IJCHM) and Tourism Management stand out, together accounting for 13 articles. In addition, the International Journal of Hospitality Management (IJHM), the Journal of Hospitality and Tourism Technology (JHTT), and the Journal of Retailing and Consumer Services also show notable representation, publishing a combined total of four articles.

*Table 2 Number of articles per journal*

Journal	No. of
International Journal of Contemporary Hospitality Management (IJCHM)	8
Tourism Management	5
International Journal of Hospitality Management (IJHM)	4
Journal of Hospitality and Tourism Technology (JHTT)	4
Journal of Retailing and Consumer Services	4
Journal of Hospitality and Tourism Management	3

Journal	No. of
Current Issues in Tourism	2
Technological Forecasting and Social Change	2
Annals of Tourism Research	1
Journal of Hospitality Marketing & Management	1
Journal of Management & Organization	1
Tourism Management Perspectives	1

Table 3 shows the classification of the methodologies used. Based on the sample ( $n = 36$ ), quantitative research constitutes the majority of the studies, with questionnaire surveys being the most common data collection method. Mixed-method approaches combining surveys and interviews, as well as purely qualitative studies, account for a smaller proportion. The most frequently used analytical technique is structural equation modeling (SEM/PLS-SEM). In recent years, longitudinal designs and cross-cultural comparisons have also been adopted to better reflect the seasonal characteristics and contextual variations of resort settings<sup>[16-24]</sup>.

*Table 3 Number of articles per research methodology*

Research Method	No. Of articles	Authors
Quantitative	28	Li et al. (2019); Liang et al. (2022); Huang & Gursoy (2024); He et al. (2023); Zhou et al. (2024)
Qualitative	5	Bhattacharyya & Nair (2019); Leavy (2019); Vatan & Dogan (2021)
Mixed	3	Sousa & Wilks (2018); Sowa et al. (2021)

### 4.3 Conceptualization and dimensionality

Scholars generally agree that employee relations possess strong interactive and organizational characteristics. They represent the psychological and behavioral responses employees develop throughout their tenure in response to a range of institutional and interpersonal stimuli<sup>[25]</sup>. Building on existing definitions, this study proposes an integrated conceptualization suitable for resort contexts: employee relations constitute a holistic, multidimensional, and dynamically evolving relational state encompassing cognitive, emotional, behavioral, and social dimensions. This state is initiated and sustained through the combined influence of organizational structures, managerial actions, and everyday interpersonal interactions, and unfolds across individual, team, and organizational levels.

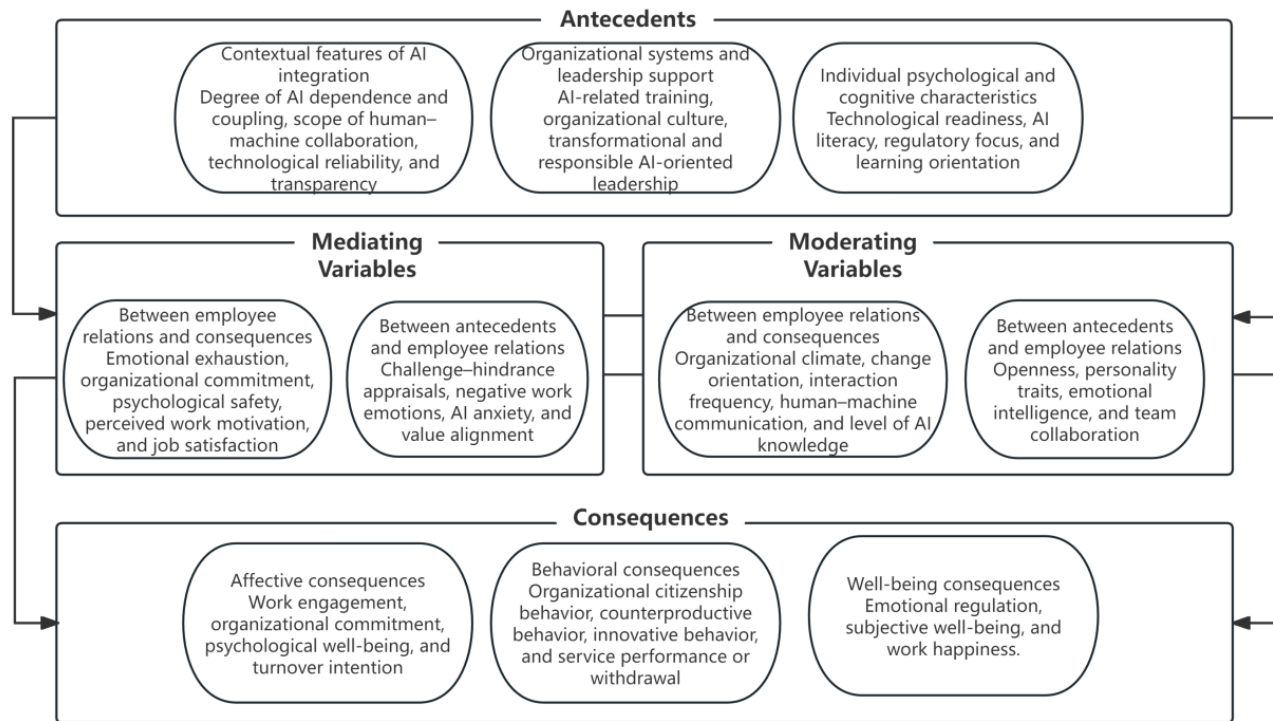
In resorts, employee relations extend across the entire employment cycle—from pre-entry expectations of a “sun-and-sand” work environment, to high-contact service interactions and emotional labor during employment, and eventually to reflections following career progression or seasonal departure<sup>[26]</sup>. With the growing integration of AI technologies, employee relations are being reshaped by the coexistence of technological and interpersonal environments. Their specific forms and interpretations are closely shaped by contextual factors unique to resorts, including seasonal employment, on-site work arrangements, and multicultural settings. This conceptualization provides a clear foundation for subsequent systematic analyses of the antecedents, dimensions, and outcomes of employee relations within the resort and AI integration context.

### 4.4 Antecedents and consequences

Academic research on employee relations in the workplace has demonstrated their multidimensional and complex nature. When the focus shifts to employee relationship management in resorts shaped by artificial intelligence technologies, however, the key antecedent and consequence variables reveal a distinct contextual specificity. Through a systematic review of the literature, this study identified twelve major antecedents and seventeen key consequences (see Figure 3). These variables reflect how the introduction of AI technologies reshapes the work environment and the patterns of human-machine interac-

tion within resorts. To clarify the core mechanisms operating under AI-enabled conditions, Figure 3 highlights the central constructs most closely related to AI awareness, human–machine collaboration, and technology integration. This framework illustrates how artificial intelligence fundamentally influences and reconfigures the dynamics of employee relations in resort contexts.

Figure 3 Summary model of resort employee relations



#### 4.4.1 Antecedents

Through a systematic review of the literature, this study identifies the key antecedents that shape employee relations in resorts under the influence of artificial intelligence. These antecedents are categorized into three core dimensions: the contextual features arising from AI integration, the organizational systems and leadership support established to manage AI-driven transformation, and the psychological and capability-related characteristics of employees as they engage with AI. This classification framework provides a structured perspective for understanding how artificial intelligence operates as a central variable that embeds within and reshapes the ecosystem of employee relations.

##### 4.4.1.1 Contextual Features of AI Integration

This category of antecedents derives directly from the characteristics of AI technologies and the ways in which they are integrated into resort operations. It represents the primary source of change driving the dynamics of employee relations. The main elements include AI dependence and event intensity<sup>[27]</sup>, work redesign through human–machine collaboration<sup>[28]</sup>, and the reliability and transparency of technology<sup>[29]</sup>. AI dependence and event intensity refer to the extent to which employees rely on AI tools within their work processes, as well as the degree of disruption, complexity, and uncertainty associated with AI technologies. High-intensity AI-related events are more likely to be perceived by employees as major transformations, triggering cognitive and emotional evaluations. The introduction of AI also redefines work roles and task boundaries, requiring employees to shift from performing routine operations toward managing, collaborating, and supporting decision-making. This fundamental change in job content constitutes a key antecedent influencing employees' attitudes and behaviors toward AI. Furthermore, the interpretability of AI systems' decision logic and the stability of their operation directly affect employees' trust in the technology.

##### 4.4.1.2 Organizational Systems and Leadership Support

This category of antecedents encompasses the systematic strategies and leadership behaviors implemented by organizations

to guide the integration of artificial intelligence. These factors function as managerial variables that mitigate technological disruption and shape constructive employee relations. The main components include AI skill training and perceived organizational support, change-oriented leadership<sup>[30]</sup>, and responsible AI principles<sup>[31]</sup>. When organizations provide structured AI training programs and clear technological support, they send a strong signal of commitment to their employees. Such practices determine whether employees can access the essential resources and confidence needed to adapt to new work models. This is particularly relevant for resorts, where short training cycles and a high proportion of seasonal employees are common. Change-oriented leadership contributes to the creation of a psychologically safe environment in which employees can engage with AI technologies, transforming technological challenges into opportunities for shared growth. In addition, transparent and fair ethical guidelines governing AI use are designed to ensure justice and accountability in technological applications. Clearly articulated standards help reduce ambiguity and potential conflict in human–machine collaboration, reinforcing employees’ perceptions of procedural fairness and strengthening their trust in the organization.

#### 4.4.1.3 Individual Psychological and Cognitive Characteristics

This category of antecedents focuses on employees’ relatively stable internal traits, which function as psychological filters through which they interpret and respond to AI technologies. These characteristics influence behavioral intentions and interaction patterns prior to any direct engagement with AI. Technological readiness reflects an individual’s intrinsic inclination to embrace new technologies, while AI anxiety captures concerns about the potential negative consequences of technological adoption. Together, these traits represent employees’ initial psychological orientation toward AI—whether they perceive it as an opportunity or as a threat<sup>[32]</sup>. They serve as foundational personality variables that shape willingness to collaborate and satisfaction with the work experience, setting the tone for human–machine interaction. According to regulatory focus theory, individual motivation can be oriented toward either promotion, emphasizing growth and accomplishment, or prevention, emphasizing security and responsibility. Employees with a promotion focus are more likely to view AI integration as an opportunity for personal development, which fosters exploratory behavior. Those guided by a prevention focus tend to emphasize potential risks and may adopt defensive coping strategies. Consequently, employees differ markedly in their adaptation trajectories and approaches to job redesign. Learning goal orientation further reflects an individual’s intrinsic motivation to acquire new skills and manage challenges. Employees with a strong learning goal orientation perceive AI integration as a valuable process for enhancing their capabilities rather than as an additional burden. This orientation functions as a key internal driver that motivates proactive learning, facilitates positive adaptation, and enables effective collaboration with AI systems.

### 4.4.2 Consequences

#### 4.4.2.1 Attitudinal Consequences

This category of consequences concerns employees’ evaluations and emotional orientations toward their work and organization. The key variables include job satisfaction<sup>[33]</sup>, organizational commitment<sup>[34]</sup>, organizational identification<sup>[35]</sup>, psychological safety<sup>[36]</sup>, and turnover intention<sup>[37]</sup>.

#### 4.4.2.2 Behavioral Consequences

This category of consequences focuses on the observable behavioral changes that emerge from employees’ experiences of AI-enabled human–machine interaction. The main variables include organizational citizenship behavior, counterproductive work behavior<sup>[38]</sup>, innovative behavior<sup>[39]</sup>, service performance<sup>[40]</sup>, retention or turnover behavior<sup>[41]</sup>, and work–family conflict or facilitation<sup>[42]</sup>.

#### 4.4.2.3 Well-being Consequences

This category of consequences centers on the effects of AI integration on employees’ psychological health and overall well-being. The key variables include emotional exhaustion and job burnout<sup>[43]</sup>, subjective well-being, and work engagement<sup>[44]</sup>.

### 4.4.3 Variables Serving as Both Antecedents and Consequences

Variables such as organizational commitment and work engagement play dual roles as both antecedents and consequences in the dynamic process of employee relations. Employee relations encompass a series of interactional touchpoints across the

entire employment cycle, from pre-entry expectations to post-employment evaluations. This process spans stages in which employees seek job information, adapt to work requirements, perform assigned responsibilities, and reflect on their career experiences. It is therefore not unexpected that some variables appear simultaneously as antecedents and consequences. In academic research, they are often conceptualized both as foundational elements in relationship formation and as outcomes that emerge from relational interactions. For example, in the hospitality sector, a high-quality supervisor–subordinate relationship serves as a strong influencing factor that shapes employees' initial expectations and work experiences<sup>[45]</sup>, thereby functioning as an antecedent of employee relations. A relationship characterized by mutual trust and support can foster favorable attitudes toward the organization. At the same time, positive employee relation experiences can strengthen employees' affective commitment; when such relationships continue to generate value and satisfaction, they enhance retention intentions and encourage extra-role behaviors<sup>[46]</sup>. Regarding variables that overlap as mediators, antecedents, and consequences, testing mediation requires first verifying a significant association between the two variables. Specifically, the independent variable (X) must influence the outcome variable (Y), and X must also affect the proposed mediating variable (M). When both X and M are entered as predictors, the mediating variable (M) should significantly affect Y<sup>[47]</sup>. Within the framework of employee relations research, such chain mechanisms of influence are common.

## 4.5 Mediating and Moderating

In research on employee relations, mediation effects have been observed primarily along two pathways: between antecedent variables and the core construct of employee relations, and between the core construct and its consequences. Along the pathway linking the core construct to its consequences, identified mediating variables include emotional exhaustion, organizational commitment, psychological safety, harmonious work passion, and job satisfaction. Along the pathway connecting antecedent variables to the core construct, mediators are often associated with employees' initial interpretations of AI and their immediate emotional responses. Examples include challenge–hindrance appraisals, which reflect whether employees perceive AI as an opportunity or a threat, an essential cognitive mechanism shaping subsequent judgments of relationship quality. Another example is negative work reflection, where post-work rumination induced by AI-related stress erodes the basis of positive employee relations. In addition, AI anxiety and trust function as critical mediators, as employees' fear of or confidence in AI technologies directly influences the initial foundation of their relationships with both the technology and the organization.

Similarly, moderating variables have been identified along both the pathway from antecedents to employee relations and the pathway from employee relations to their consequences. On the latter pathway, a larger number of moderators have been found, including organizational support factors such as perceived organizational support and change-oriented leadership. These variables can mitigate the adverse impact of negative relationships and enhance the benefits of positive ones. Individual characteristics also serve as moderators, including employees' promotion or prevention focus, resilience, and level of AI knowledge, which influence how employees manage stress or seize opportunities within specific relational contexts. Moderators situated between antecedent variables and employee relations are likewise associated with personal traits and organizational contextual factors. Examples include openness and neuroticism, as well as situational elements such as a competitive psychological climate and the quality of team collaboration.

## 5. Agenda and future research

### 5.1 Exploration of Moderating Variables in AI Contexts

Moderating variables are essential for understanding how artificial intelligence differentially influences employee relations, as they define the boundary conditions of the relationship between AI applications and employee outcomes. In the specific context of resorts, the type and depth of AI application—such as substitutive AI for automated front-office services, collaborative AI in housekeeping robots, or analytical AI for personalized guest preference prediction, may themselves function as key moderating variables. Different forms of AI influence employees' job content, skill requirements, and psychological perceptions in distinct ways, potentially moderating the strength of the association between AI awareness or AI dependence and employee relational outcomes.

Given the diversity of service roles within resort operations, employees' acceptance, evaluation, and emotional or behavioral



responses to AI technologies may vary according to department, frequency and depth of guest interaction, and the resort's market positioning. For example, employees in luxury resorts may perceive AI as an enabling tool that enhances personalized service, whereas those in large, efficiency-oriented resorts may regard it as a potential threat to their job security. Analyzing such contextual moderating effects can provide a more precise assessment of the dual impact of AI adoption in the complex service environment of resorts.

Existing studies have begun to examine the moderating roles of individual traits and organizational factors, yet research addressing moderators specific to resort settings remains limited. Future studies should focus on the nature of human, AI collaboration, whether substitutive, assistive, or augmentative, and consider factors such as algorithmic transparency and controllability, the distinctive "joyful atmosphere" of resort organizational culture, and the moderating role of seasonal work pressures. Employing research designs that capture dynamic processes, such as longitudinal comparisons between peak and off-peak seasons, could offer valuable insight into how these moderating variables influence the evolution of employee relations and well-being across different stages of AI integration.

## 5.2 Exploration of Mediating Mechanisms in AI Contexts

This systematic literature review highlights the need for deeper investigation into the internal mechanisms that link antecedent variables to employee relational outcomes in AI-driven work environments. Current research on these mediating variables remains in an early stage, with only a limited number of variables having been preliminarily examined, such as job insecurity, emotional exhaustion, and job crafting. Existing findings suggest that employees' perceptions and experiences of AI do not directly determine behavioral outcomes; rather, they operate through complex processes that influence psychological states and work patterns.

Most existing studies have focused on identifying psychological or behavioral variables that mediate the relationship between AI perception and negative outcomes, while potential positive mediating pathways have received comparatively little attention. For instance, possible mechanisms such as enhanced job autonomy, psychological empowerment, and harmonious work passion may explain how AI integration fosters proactive service behavior or innovation, yet these pathways remain underexplored. Within the resort context, where work is inherently creative and experience-oriented, examining such positive mediators is of particular importance.

Although employees' perceptions of human-AI collaboration quality have been shown to exert direct effects on work outcomes<sup>[48]</sup>, the mechanisms through which this perception mediates the influence of organizational AI strategies on employee relational states are still unclear. For example, when resort management introduces service robots, understanding how this initiative shapes employees' daily collaboration experiences with robots, and how these experiences ultimately affect organizational commitment, remains an open question. Identifying and verifying mediating variables that play a critical role in the distinctive work environment of resorts is therefore essential.

Moreover, employees' challenge appraisals of AI have been examined as antecedent variables that influence service performance through the mediating role of job crafting. This indicates that employees' overall cognition and interpretation of AI may themselves serve as core mediating constructs. Future studies should systematically examine the conditions under which the quality of the employee-AI relationship functions as a mediator, and between which organizational antecedents and individual consequences it exerts this influence. Such inquiry would contribute to building a more comprehensive and dynamic framework for understanding how AI becomes embedded in and reshapes the ecosystem of employee relations in resorts.

## 5.3 Focusing on the Dual-Edged Effects of Artificial Intelligence

Existing research has largely concentrated on the positive impacts of artificial intelligence and the conditions that facilitate them, such as enhancing work efficiency, promoting job crafting, or fostering employee creativity. However, limited understanding remains regarding the potential negative experiences that may arise from AI integration and their broader consequences. As studies on job insecurity and emotional exhaustion have indicated, future research needs to shift toward examining how organizations can manage AI effectively while mitigating its adverse effects. This line of inquiry should explore the underlying factors that generate negative experiences and the mechanisms through which these experiences lead



to undesirable outcomes such as counterproductive work behavior, work disengagement, or job burnout.

#### **5.4 Focusing on the Antecedents of Employees' AI Experiences**

Although previous studies have identified certain antecedents influencing employees' experiences with artificial intelligence, most have focused on cognitive factors. Research addressing affective antecedents, such as initial attitudes toward technology, emotional traits, and deeper organizational or environmental drivers, remains limited. Questions therefore arise as to whether, and in what ways, distinctive features of resort organizations, such as a "joyful atmosphere" culture, inclusive leadership communication during technological transformation, corporate social responsibility initiatives, and the physical as well as technological environment of the resort, shape employees' acceptance and experiences of AI. Given that new forms of smart tourism are prompting firms to make substantial investments in AI, the Internet of Things, and big data analytics, it is important to examine how the intrinsic characteristics of these technologies interact with their organizational implementation contexts to influence employees' AI experiences. Such investigation can inform the design of AI integration strategies that are more human-centered and better aligned with employees' expectations and working realities.

#### **5.5 Expanding and Innovating Research Methods**

In methodological terms, current studies have relied heavily on survey-based data collection, while other approaches that can reveal causal mechanisms or provide deeper contextual understanding—such as experimental designs, qualitative interviews, and longitudinal tracking—remain underutilized. It is therefore necessary to adopt more innovative or mixed-method approaches to investigate this phenomenon in a comprehensive and dynamic manner, thereby improving the accuracy and reliability of research findings. For instance, experience sampling and diary studies can capture employees' daily emotional fluctuations, stress levels, and coping strategies during interactions with AI, making them particularly suitable for examining adaptation processes under the seasonal workload conditions of resorts. Experimental research can simulate various human-AI collaboration scenarios to test causal relationships that have so far been inferred primarily through structural equation modeling. Qualitative approaches, including ethnographic or action research, can provide situated insights by observing how AI is embedded into and transforms existing work practices, communication patterns, and social networks within resort operations. In addition, big data analytics may be employed to examine log data generated from employee-AI interactions or to analyze discussions related to AI on internal communication platforms, enabling objective, large-scale identification of behavioral patterns and emotional tendencies.

#### **5.6 Digital Work Platforms and Employee Relational Experiences**

Although internal digital work platforms and emerging generative AI tools are becoming increasingly prevalent in the hospitality industry, serving as essential channels for employees to communicate, share knowledge, and access organizational information, no study has yet systematically examined employee relational experiences in resorts from this perspective in the age of AI. These platforms function not only as tools for task management but also as spaces that shape organizational climate, convey corporate culture, and influence employees' social connections.

#### **5.7 Expansion and Innovation of Theoretical Frameworks**

The literature reviewed in this study shows that theoretical frameworks explaining the mechanisms linking artificial intelligence and employee relations remain relatively concentrated, relying primarily on classical theories such as the stress-appraisal theory<sup>[49]</sup>, conservation of resources theory<sup>[50]</sup>, and social exchange theory<sup>[51]</sup>. To achieve a more comprehensive understanding of this complex phenomenon, future research should incorporate more diverse and contemporary theoretical perspectives, adopting a multidisciplinary approach that draws from information technology adoption, organizational behavior, and human-computer interaction. Relevant frameworks may include the Unified Theory of Acceptance and Use of Technology (UTAUT), job crafting theory, human-AI collaboration theory, and social information processing theory. Integrating and cross-applying these perspectives would allow research to move beyond existing conceptual boundaries and more precisely reveal how AI interacts with individuals, teams, and organizations within the unique service ecosystem of resorts, thereby uncovering the mechanisms through which employee relations are reshaped.

### **6. Conclusion**

This study proposes an integrated conceptual framework that clarifies the core mechanisms and boundary conditions of

employee relationship management in resorts within the era of artificial intelligence.

## 6.1 Theoretical Implications

This systematic review enhances the understanding of the construct of employee relations within the specific context of resorts by clarifying its dimensions and manifestations in service-oriented, high-interaction environments. It identifies the distinctive characteristics of employee relations in such settings and highlights the methodological tendency of existing studies to rely predominantly on cross-sectional surveys. The review thus points to opportunities for future research employing longitudinal, experimental, qualitative, and mixed-method designs. Furthermore, this study systematically organizes and integrates factors identified in prior research that relate to employee relations in AI-enabled contexts, improving the understanding of how these factors influence one another and the reciprocal mechanisms involved. Finally, it offers a structured classification of the antecedents and consequences associated with AI's influence on employee relations.

The analysis of existing literature reveals two main research trajectories in this field. The first represents a generalist line of inquiry, which focuses on examining how artificial intelligence, as a pervasive technological stressor, influences employees' psychological states. This stream of research is primarily grounded in theories such as conservation of resources and the job demands–resources model. The second trajectory takes a contextualized perspective, emphasizing how the distinctive operational characteristics of resorts interact with AI technologies to shape unique dynamics of employee relations. This distinction helps scholars construct theoretical models that align with their specific research focus. Building on an integrated analysis of existing definitions and dimensions, this study proposes a conceptual framework for employee relationship management in the age of AI, tailored to the characteristics of the resort industry. The framework's value lies in its incorporation of the key elements most relevant to this context, including AI event intensity, employees' psychological appraisal processes, and the moderating influence of organizational conditions, thereby offering a coherent structure for examining these interactions. The review also identifies several research gaps. Empirical studies addressing how emerging technologies such as generative AI or sustainability-oriented practices specific to resorts influence employee relations remain limited. This observation differs from findings in broader hospitality research, which tend to identify a wider range of technology-related drivers. However, those studies encompass diverse formats, from limited-service to full-service operations, making their conclusions less precise for the resort segment. By focusing on the more homogeneous resort context, the present study enables the identification of specific and unresolved issues, allowing for the formulation of actionable insights that can inform managerial practice and open research avenues often overlooked in broader, more heterogeneous hospitality markets.

## 6.2 Practical Implications

This study offers guidance for resort managers on how to design positive and supportive employee relationship management strategies in the era of artificial intelligence. The synthesis of potential negative outcomes associated with AI awareness highlights the importance for managers to recognize and address the psychological impacts of technological transformation on employees. In addition, the integrated analysis of mediating mechanisms and moderating variables provides actionable leverage points for managerial intervention, enabling more precise improvements in management practices. Understanding the antecedents and consequences identified in this study can provide resort managers with a competitive advantage, helping them to plan AI integration strategies systematically and to optimize the employee experience through communication, training, and organizational culture. For instance, if a resort's brand identity emphasizes employee care or leadership in green technology, this core value should be embedded in the AI adoption process. Managers could design environmentally friendly human–AI collaboration workflows or provide informational materials illustrating how AI can reduce repetitive physical tasks and optimize energy use. Such initiatives can empower employees to focus on creative service delivery and sustainable practices that add greater value. Framing AI as an enabling innovation rather than a replacement threat is also critical. Through internal communication, resorts can present AI as a tool that enhances service quality and supports employees in understanding guest preferences and anticipating service needs. This framing can help create positive psychological expectations among employees and reduce resistance to technological change. Equally important is the establishment of open and transparent feedback channels, ensuring that employees' concerns receive timely responses and appropriate support. Such practices can strengthen employees' perceptions of organizational support and help buffer the uncertainty and stress associated

with AI integration.

### 6.3 Limitations and Future Research

The literature search and analysis in this study were primarily based on the Web of Science and Scopus core databases. Although a systematic literature review approach was employed to ensure methodological rigor and replicability, the selected sample may not fully capture all relevant studies in this research domain. Future work could expand the search to additional specialized databases or include publications in other languages to achieve a broader and more comprehensive perspective. This study primarily conducted a qualitative synthesis and evaluation of existing research. Future studies may adopt alternative methodological approaches, such as meta-analysis, to quantify the effect sizes of specific variable relationships, or bibliometric analysis to map the structural and evolutionary patterns of knowledge in this field. Comparative studies that examine resorts alongside other service industries, such as fine dining or theme parks, could help identify the contextual particularities of AI's influence on employee relations. Moreover, exploring variations among different types of resorts or across employee groups in their responses to AI technologies would provide valuable insights. Such focused investigations may yield more context-specific managerial implications. The conceptual framework proposed in this study also requires empirical validation. Future research could test and refine the framework's pathways through quantitative surveys, qualitative interviews, or case studies, paying particular attention to mediating and moderating mechanisms. These efforts would advance the study of employee relationship management in AI-enabled resort contexts toward greater theoretical maturity and analytical precision.

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### Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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# A Comparative Analysis of Cross-Border E-commerce Payment Tools and User Profiling for Shadow Puppetry Intangible Cultural Heritage

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**Abstract:** With the booming development of cross-border e-commerce, the international sales of shadow puppetry intangible cultural heritage products have gained new opportunities, where the application of fintech tools plays a crucial role. This paper conducts a comparative analysis of operational efficiency and risk control differences between shadow puppetry e-commerce enterprises that utilize cross-border payment systems, supply chain finance, and robo-advisory tools, and those that do not. By leveraging cross-border e-commerce platform data, the study delves into user characteristics across different age groups, interests, and geographic demographics, ultimately designing targeted fintech marketing strategies. These efforts aim to enhance financial service capabilities for shadow puppetry e-commerce and promote its sustainable growth in international markets. The research demonstrates that strategic fintech applications can significantly improve operational efficiency and risk management for overseas enterprises, while precision marketing solutions effectively attract target audiences and expand market share.

**Keywords:** Shadow Puppetry Intangible Cultural Heritage; Cross-Border E-commerce; Payment Tools; User Profiling; Fintech

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## 1.Introduction

Amid the deep integration of globalization and the digital economy, cross-border e-commerce has emerged as the driving force behind China's foreign trade transformation. According to data from the General Administration of Customs, China's cross-border e-commerce import and export volume reached 2.63 trillion yuan in 2024, marking a 10.8% year-on-year increase that significantly outpaced the overall foreign trade growth rate during the same period. Meanwhile, the commercialization and internationalization of intangible cultural heritage continue to accelerate. Shadow puppetry, a traditional art form with over two millennia of history, combines painting, carving, music, and performance into a unique cultural treasure. Its profound cultural heritage and distinctive aesthetic value are gradually unlocking cross-border sales potential.

But shadow puppetry is an intangible cultural heritage<sup>[1]</sup>Cross-border e-commerce continues to face multiple practical challenges: cultural barriers in market perception, difficulties in aligning manual production with cross-border logistics, inefficient payment settlement systems, and insufficient understanding of target market demands. Among these, the

compatibility of financial services and precise alignment with user needs have become critical constraints. The security, timeliness, and cost-effectiveness of cross-border payments directly impact transaction conversion efficiency, while gaps in understanding overseas users lead to wasted marketing resources and hinder effective market penetration. Against this backdrop, innovative applications of fintech tools and precise user profiling offer new pathways for the sustainable development of shadow puppetry's cross-border e-commerce as an intangible cultural heritage.

### 1.1 Research Significance

The theoretical significance of this study lies in filling existing research gaps: While current academia predominantly focuses on comparing cross-border e-commerce payment tools or marketing models for single intangible cultural heritage (ICH) products, systematic analysis of fintech tools impact on enterprise operations for categories with strong cultural attributes and unique product forms—such as shadow puppetry—along with user profiling-based service optimization remains relatively scarce. Grounded in the distinctive characteristics of shadow puppetry ICH, this study integrates fintech applications with cross-border user profiling analysis. By enriching the research framework for ICH cross-border e-commerce, it reveals the practical value and operational mechanisms of fintech in specific scenarios, providing new perspectives for related academic research.

In practical terms, research findings can directly serve industrial development: They provide payment tool selection guidance for cross-border e-commerce enterprises in the shadow puppetry intangible cultural heritage sector, helping reduce transaction costs and manage cross-border risks. Additionally, they enable the design of targeted marketing strategies based on user profiles, enhancing market promotion efficiency and user retention. Furthermore, the research conclusions can inform government policies supporting the global expansion of intangible cultural heritage and assist financial institutions in optimizing cross-border services, ultimately achieving a win-win outcome for both cultural dissemination and commercial value of shadow puppetry.

### 1.2 Research status

A review of global and domestic research reveals distinct priorities: international studies emphasize security and cost control in cross-border e-commerce payment tools, while domestic research focuses on applicability and risk management. In the realm of intangible cultural heritage (ICH) cross-border e-commerce, foreign scholars prioritize international market acceptance of cultural products, whereas domestic research concentrates on development models and marketing strategies. Regarding user profiling applications, international studies have accumulated extensive big data modeling expertise, while domestic research predominantly targets general product categories. However, existing studies exhibit three critical limitations: lack of specialized research on shadow puppetry ICH, insufficient integration of fintech with user profiling, and weak empirical data support. This study establishes theoretical foundations through literature review, conducts case analyses of representative enterprises, and employs cross-border platform transaction data for empirical verification. By applying comparative analysis to clarify tool value and user differences, we construct an integrated framework of “tool comparison-user insights-solution optimization,” achieving innovative advancements in research perspectives, methodologies, and practical applications.

## 2.Relevant Theoretical Basis

Cross-border e-commerce refers to international commercial activities where trading entities from different customs territories conduct transactions through e-commerce platforms, complete electronic payment settlements, and deliver goods via cross-border logistics. Its core characteristics include globalized transactions, digitized processes, and cross-border logistics. The theoretical framework encompasses transaction cost theory, long-tail theory, and platform economy theory. Transaction cost theory suggests that cross-border e-commerce significantly reduces information search and fulfillment costs by simplifying processes and eliminating intermediaries, enabling niche intangible cultural heritage products like shadow puppetry to break geographical barriers and reach global target audiences. Long-tail theory indicates that the combined market potential of niche products in the internet era can rival mainstream products. Through the aggregation effect of cross-border e-commerce, shadow puppetry can meet global niche demands and achieve economies of scale. Platform economy theory emphasizes that cross-border e-commerce platforms lower entry barriers through improved regulations and services, allowing shadow

puppetry enterprises to rapidly enter international markets by leveraging platform traffic.

FinTech (Financial Technology) is an innovative business model that leverages big data, artificial intelligence, blockchain, and other technological advancements to enhance financial services. Its core objectives are to improve efficiency, reduce costs, and strengthen security, encompassing three key theories: technology-driven theory, financial innovation theory, and risk control theory. The technology-driven theory posits that big data provides precise credit evaluation for shadow enterprises supply chain financing, while artificial intelligence optimizes capital allocation recommendations. Financial innovation theory highlights how real-time exchange rate conversion for cross-border payments and digitalized supply chain processes can precisely meet the operational needs of shadow enterprises in global markets. Risk control theory demonstrates that blockchains tamper-proof characteristics combined with intelligent risk monitoring systems can enhance operational efficiency while effectively managing transaction risks.

User profiling is a virtual model constructed through data collection and analysis, with its core value lying in accurately understanding user needs. The theoretical framework encompasses three key components: data acquisition, feature extraction, and profile application. The data acquisition theory emphasizes integrating multidimensional data including demographics, behavioral patterns, and preference preferences. For shadow puppet e-commerce, it specifically requires collecting user preferences regarding themes and craftsmanship. The feature extraction theory focuses on extracting core attributes from massive datasets, such as identifying purchasing frequency and price preference characteristics of high-value users. The profile application theory advocates integrating user profiles with business scenarios to enhance conversion efficiency through personalized recommendations and targeted marketing.

### **3.Development Status of Cross-Border E-Commerce of Shadow Puppetry Intangible Cultural Heritage and Application of Fintech Tools**

The cross-border e-commerce of shadow puppetry, a UNESCO Intangible Cultural Heritage, currently operates through three primary models. The first involves listing on global platforms like Amazon, eBay, and Alibaba International Station, leveraging their massive traffic to drive sales. This approach, with its low entry barriers and quick returns, has become the preferred choice for most small and medium-sized shadow puppetry businesses. The second model focuses on building dedicated e-commerce sites, utilizing social media platforms like Facebook and Instagram to showcase traditional craftsmanship and performance videos, ideal for companies with established brand recognition. The third strategy partners with overseas cultural institutions such as museums and art galleries, combining customized product sales with cultural exhibitions to significantly enhance cultural value. In terms of target markets, Europe and America dominate as consumers in these regions demonstrate strong cultural affinity and purchasing power for Eastern traditions. Southeast Asia is experiencing rapid growth through geographical and cultural proximity coupled with efficient logistics. Meanwhile, Japan and South Korea maintain stable demand due to their appreciation for traditional craftsmanship.

The industry still faces three core challenges. In payment processing, traditional wire transfers suffer from lengthy processing times and high fees, while payment methods remain underdeveloped in certain markets—such as Southeast Asian users preferred e-wallet channels that are not fully integrated. Regarding market positioning, companies lack clear understanding of overseas user needs, resulting in product and marketing homogenization that fails to account for regional cultural preferences. Supply chain issues include time-consuming shadow puppet production, inconsistent cross-border logistics, and delayed responses from traditional supply chain financing, making it difficult to meet capital turnover demands.

Fintech tools<sup>[2]</sup>The application of shadow puppetry in cross-border e-commerce has formed a differentiated landscape: In cross-border payment sectors, third-party platforms like PayPal have become mainstream choices due to their multi-currency support and short settlement cycles. Their commercial collection rates range between 3.4%-4.4%, with fixed fees per transaction and mandatory handling fees for withdrawals to domestic accounts. Blockchain payments, despite offering lower fees (0.5%-1%) and minute-level settlement times, remain limited to large transactions due to user unfamiliarity. Traditional wire transfers continue to shrink in application due to high costs and delayed processing. In supply chain finance, order financing has gained popularity among shadow puppetry enterprises for its quick application and disbursement processes, allowing companies to secure loans for raw material procurement through platform orders. Warehouse receipt pledge

financing, however, remains underutilized as shadow puppetry products are difficult to value, with most SMEs still relying on self-funded operations and weaker risk resilience. Regarding smart tools, high-threshold robo-advisors are adopted mainly by medium-to-large enterprises for fund management, while intelligent risk control tools are more widely used to monitor abnormal transactions and reduce fraud risks. Companies without these tools exhibit significantly higher risk incidence rates compared to their users.

#### **4.Comparative Analysis of Cross-border E-commerce Fintech Tools for Intangible Cultural Heritage Shadow Puppetry**

Among cross-border payment solutions, third-party payment systems demonstrate the most comprehensive advantages. Platforms like PayPal, which operate globally across major markets, support multi-currency settlements with 1-3 day processing times. While their fees exceed blockchain-based solutions, they align well with shadow puppet product manufacturers preference for small-to-medium transactions and enjoy high user acceptance. Blockchain payments excel in high-value transactions, offering near-real-time processing and competitive fees that meet demands like overseas theater procurement orders. However, limited market awareness and regulatory constraints prevent full-scale adoption. Traditional wire transfers remain suitable only for large supplier settlements with low time sensitivity. Their 3%-5% fees and 3-7 day processing cycles no longer meet shadow puppet enterprises capital turnover requirements.

Among supply chain financial instruments, order financing proves most suitable for shadow puppet enterprises. This tool requires only platform-verified orders and business licenses for application, with a 1-2 day disbursement cycle and financing coverage reaching 60%-80% of order value. The funds are specifically allocated for raw material procurement, precisely aligning with shadow puppet production cycles of 15-30 days. In contrast, warehouse receipt pledge financing demands complex documentation including warehouse receipts and valuation reports, with a 3-5 day disbursement period and financing coverage limited to 50%-60% of goods value. Due to the significant variations in shadow puppet craftsmanship complexity, valuation challenges make this financing method only applicable for temporary working capital needs of enterprises with excess inventory.

Comparative analysis of intelligent tools reveals that smart risk control systems demonstrate broader applicability. Their core functions—fraud detection and credit risk assessment—effectively maintain low fraud rates without requiring specific enterprise size, making them particularly suitable for small and medium-sized shadow enterprises with weaker risk resilience. In contrast, robo-advisors primarily provide capital allocation recommendations for medium-to-large enterprises with substantial annual transaction volumes. While these tools can enhance annualized returns by 1%-2% and reduce foreign exchange losses, they show relatively low demand among most small and medium-sized shadow enterprises.

#### **5.Empirical Analysis of Cross-Border E-commerce User Profiles of Shadow Puppetry Intangible Cultural Heritage**

Based on cross-border e-commerce platform transaction data and market research reports on intangible cultural heritage (ICH) products, the core characteristics of ICH cross-border users can be defined through three aspects. Demographically, the age distribution shows significant concentration, with users aged 25-45 forming the core group. Notably, the proportion of 18-30 year-olds has increased significantly. Data from 2024 indicates that 40% of ICH product buyers are post-95s generation, a demographic that values cultural identity while pursuing social attributes. Geographically, users from Europe and America account for the largest share, with the United States, United Kingdom, and Germany being primary source countries. Southeast Asian markets like Indonesia and Malaysia are experiencing rapid growth, while Japan and South Korea maintain stable market shares. Regarding income levels, middle-to-high-income groups earning over \$8,000 monthly constitute the main consumer base, demonstrating stronger willingness to pay for high-quality shadow puppet products.

In terms of consumer behavior characteristics, purchase frequency shows seasonality<sup>[3]</sup>The purchasing patterns show distinct regional variations. During holiday gift shopping and cultural events, users with an average of 2-3 annual purchases dominate the market. Price preferences indicate a clear hierarchy: mid-range products (US\$500-2000 per order) account for over 70% of transactions, while premium customized items primarily target collectors. Payment methods reveal regional preferences:

PayPal remains the top choice for Western users (over 50% of transactions), whereas Southeast Asian consumers prefer local e-wallets like GrabPay and Gcash, with credit cards and bank transfers being less common.

In terms of interest preferences, product demand exhibits a dual trend of traditional and innovative elements. Classic historical themes like “Journey to the West” and “Romance of the Three Kingdoms” remain dominant, while customized products such as family portraits and corporate shadow puppet logo designs are experiencing rapid growth. Regarding purchasing motivations, cultural collectibles and holiday gift-giving account for over 70% of purchases, reflecting users high recognition of shadow puppet cultures value. For information acquisition, social media dominates with Facebook and Instagram driving 50% of traffic, followed by cross-border platform recommendations and cultural websites, while recommendations from friends and family are the least popular.

## 6.Design of Fintech Marketing Solutions Based on User Profiles

Product promotion requires tailored strategies for different user groups: For core users aged 25-45 in Europe and America, share shadow puppetry short videos and cultural stories on Facebook and Instagram. Leverage AI-powered business assistants on platforms like Alibaba International Station to optimize product detail pages, boost search visibility, and launch a “Shadow Puppet Products + Online Intangible Cultural Heritage Courses” collection package. For Southeast Asian users, design themed products aligned with local festivals like Eid al-Fitr and Songkran, and push discount information through local e-wallet channels. For high-frequency buyers, establish a membership system offering exclusive customization services and priority access to cultural events.

Payment service optimization<sup>[4]</sup>Prioritize adaptability and security: To address regional preference differences, we will enable multi-channel payment interfaces between PayPal and Southeast Asian local e-wallets. Users paying through local e-wallets will enjoy reduced fees to boost payment conversion rates. For customized orders exceeding \$2,000 per transaction, we will introduce blockchain payment options highlighting their “10-minute settlement” advantage, along with real-time payment progress tracking. A comprehensive smart risk control system will be deployed to monitor suspicious transactions in real-time, with secondary verification through SMS codes. We will also publicly disclose our “Zero Loss for Fraudulent Transactions” policy to strengthen user trust.

Supply chain finance must precisely align with enterprise needs: To support stable orders from core users, we promote order financing services for shadow puppet production enterprises by simplifying application procedures. Businesses only need to upload platform orders and business licenses to complete the process, with loan disbursement within 24 hours. First-time users receive preferential interest rates. Through partnerships with overseas warehouses, we establish standardized evaluation systems for shadow puppet products, setting assessment criteria based on production complexity and market popularity. This enhances the efficiency of warehouse receipt-backed financing, while providing targeted financial support for inventory overstock products during holiday seasons.

The implementation of the plan requires establishing a three-tiered safeguard system: Technologically, we collaborate with licensed fintech companies to ensure stable operation of payment interfaces and risk control systems, while regularly updating algorithms to adapt to market changes. Data-wise, we strictly comply with the EU GDPR and Southeast Asian personal information protection regulations, establishing data security management and backup mechanisms to protect user information. In terms of training, we provide fintech tool usage training covering payment system operations and financing application processes, while offering 24/7 online customer support to promptly resolve enterprise issues.

## 7.Research Conclusions and Prospects

The study demonstrates that fintech tools significantly enhance operational efficiency in cross-border e-commerce for shadow puppetry, a UNESCO Intangible Cultural Heritage. Third-party payment solutions reduce costs by 30%-40% and cut processing times by 60%-70% compared to traditional wire transfers. Companies utilizing order financing achieve 50% faster capital turnover and 25% higher order fulfillment rates, while implementing smart risk control systems further optimizes operations.<sup>[5]</sup>Enterprises with fraud risk mitigation systems demonstrate significantly lower fraud rates compared to those relying on manual audits. The core cross-border shadow puppetry intangible cultural heritage users exhibit distinct



characteristics: predominantly middle-to-high-income individuals aged 25-45 from Western countries, who prefer traditional themes and mid-range products. Their purchasing motivations focus on collecting and gifting, while they actively seek information through social media and utilize third-party payment platforms. A user profiling-based fintech marketing strategy, combining targeted promotions, payment optimization, and financial support, can effectively enhance corporate market share and customer satisfaction.

This study has two limitations: First, user data primarily originates from mainstream cross-border platforms, with insufficient coverage of emerging markets and independent site users. Second, the impact of cultural differences on users acceptance of financial tools remains underanalyzed, requiring further validation of the solutions cross-cultural adaptability. Future research should expand data sources to include multiple platforms and emerging markets, enhancing the generalizability of conclusions. It should also explore the mechanisms behind cultural influences to optimize regional adaptability of solutions. Additionally, investigating new technologies like metaverse exhibition halls and virtual payment systems could improve user experience through immersive shadow puppet performances, thereby promoting deeper global dissemination of shadow puppet culture.

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The authors declare that there is no conflict of interest regarding the publication of this paper.

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# Research on the Pathways of Digital Transformation Empowered by Technology for the Foreign Trade Business of Technology Enterprises

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**Abstract:** With the rapid advancement of information technology, digital transformation has become an essential path for enterprise survival and development. As a vital force driving socio-economic development, the success or failure of the digital transformation of technology enterprises' foreign trade business not only concerns their own survival and development but also significantly impacts the innovation capability and production efficiency of the entire industry and even society. Therefore, exploring the pathways for technology to empower the digital transformation of foreign trade business in technology enterprises is particularly important. This paper is mainly divided into the following parts: Part I is the introduction, explaining the research background and significance; Part II analyzes the current state of foreign trade business in technology enterprises; Part III discusses the problems existing in the foreign trade business of technology enterprises; Part IV provides countermeasures and suggestions; Part V is the conclusion.

**Keywords:** Technology Empowerment; Technology Enterprises; Foreign Trade Business; Digitalization; Transformation Pathways

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## 1.Introduction

### 1.1 Research Background

In recent years, China has attached great importance to technological advancement and digital development. The report of the 20th National Congress of the Communist Party of China proposed to “accelerate the implementation of the innovation-driven development strategy”. The “2023 China Digital Economy Development Research Report” shows that in 2022, China’s digital economy reached 50.2 trillion yuan, accounting for 41.5% of the GDP. Digital transformation is the inevitable path for enterprises to follow the trend of the times and achieve high-quality development. According to the data from the Zhongguancun Information Technology and Real Economy Integration Development Alliance (CITIA), as of 2023, 10.15% of enterprises have entered the substantive transformation stage, and the maturity level index of enterprise digital transformation is 29.29, an increase of 27.85% compared with 2021, with an average growth rate of 13.07% over the past three years. A large number of studies have shown that through digital transformation, enterprises can not only improve operational efficiency, innovate business models, optimize decision support and management levels, but also build a customer-centered corporate culture, and achieve value enhancement in promoting sustainable development and fulfilling

social responsibilities<sup>[1]</sup>.

As a significant force driving the advancement of global technology, the transformation of foreign trade business for technology enterprises has become an essential part of their sustainable development. In the rapidly changing market environment, technology enterprises need to constantly seek new ways and methods for the transformation of their foreign trade business to adapt to the global competitive situation. From deepening domestic operations to expanding into international markets, the transformation and expansion of foreign trade business for technology enterprises not only concerns their survival and development but also their position and influence in the global industrial chain and value chain. Against this backdrop, the exploration of transformation paths for the foreign trade business of technology enterprises is particularly important. This article studies the digital transformation paths and practices of foreign trade business for technology enterprises empowered by technology<sup>[2]</sup>.

## 1.2 Research Significance

From the perspective of enterprise operation, the transformation paths distilled in this study have been verified in leading domestic technology enterprises. For instance, Huawei has shortened its overseas delivery cycle through digital twin technology (2022 Annual Report), and DJI has enhanced its customs declaration efficiency by leveraging an intelligent supply chain system (2023 Case Collection), providing replicable solutions for the industry. From the perspective of policy-making, this research offers a basis for government departments to improve digital trade infrastructure. More profoundly, by promoting the digital upgrade of foreign trade operations in technology enterprises, it is expected to drive efficiency improvements across the entire upstream and downstream industrial chain, playing a crucial supporting role in achieving the “Digital China” strategy<sup>[3]</sup>.

## 2. Analysis of the Current Situation of Foreign Trade Business of Technology Enterprises

### 2.1 Overview of Current Foreign Trade Business

#### 2.1.1 Export scale

With the continuous advancement of technology and the constant innovation of products, the competitiveness of the products of technology enterprises in the international market has gradually increased. This has driven the expansion of export scale, especially in high-tech fields such as integrated circuits, new energy vehicles, lithium batteries, and 3D printers. From an overall trend perspective, the total export volume has grown from 9.15 trillion yuan in 2019 to 23.08 trillion yuan in 2024. From the perspective of structural changes, in 2019, integrated circuits accounted for 77% (dominant position), and in 2024, integrated circuits will account for 49.2% and new energy vehicles 27.8% (a dual-pillar pattern). For specific data, please refer to Table 1.

*Table 1 Changes in the Scale of Main Export Products of Technology Enterprises from 2019 to 2024* Unit: Yuan

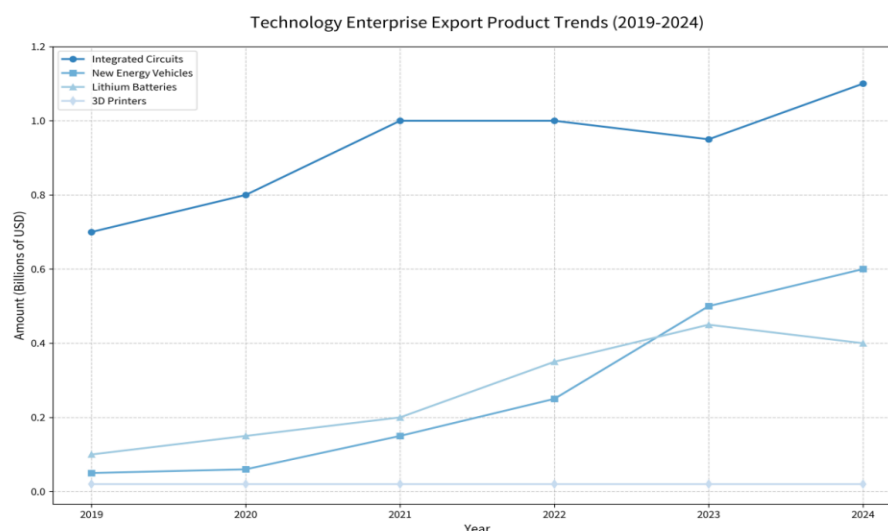
	<b>Integrated circuits</b>	<b>New energy vehicles</b>	<b>Lithium batteries</b>	<b>3D printers</b>
2019	704,438,942,294	59,565,976,250	116,368,357,625	34,511,472,364
2020	808,324,230,228	68,648,586,390	139,489,221,571	34,917,184,099
2021	995,777,282,604	157,582,070,288	214,991,437,719	42,482,553,513
2022	1,011,052,147,181	301,111,369,458	382,993,549,586	42,066,724,251
2023	959,100,761,711	547,626,665,184	491,396,538,370	45,806,930,670
2024	1,136,433,530,862	641,656,399,626	473,925,614,748	56,030,074,042

Data source: General Administration of Customs

From the perspective of different products, the proportion of integrated circuits increased by 14.7% year-on-year in 2020, 23.2% in 2021, 1.5% in 2022, 5.1% in 2023, and 18.5% in 2024. The number of new energy vehicles increased by 15.2% year-on-year in 2020, 129.6% in 2021, 91.1% in 2022, 81.9% in 2023, and 17.2% in 2024. The lithium battery market increased by 19.9% year-on-year in 2020, 54.1% in 2021, 78.1% in 2022, 28.3% in 2023, but decreased by 3.6% in 2024. 3D

printers increased by 1.2% year-on-year in 2020, 21.7% in 2021, 1.0% in 2022, 8.9% in 2023 and 22.3% in 2024. The specific trend chart can be referred to in Figure 1.

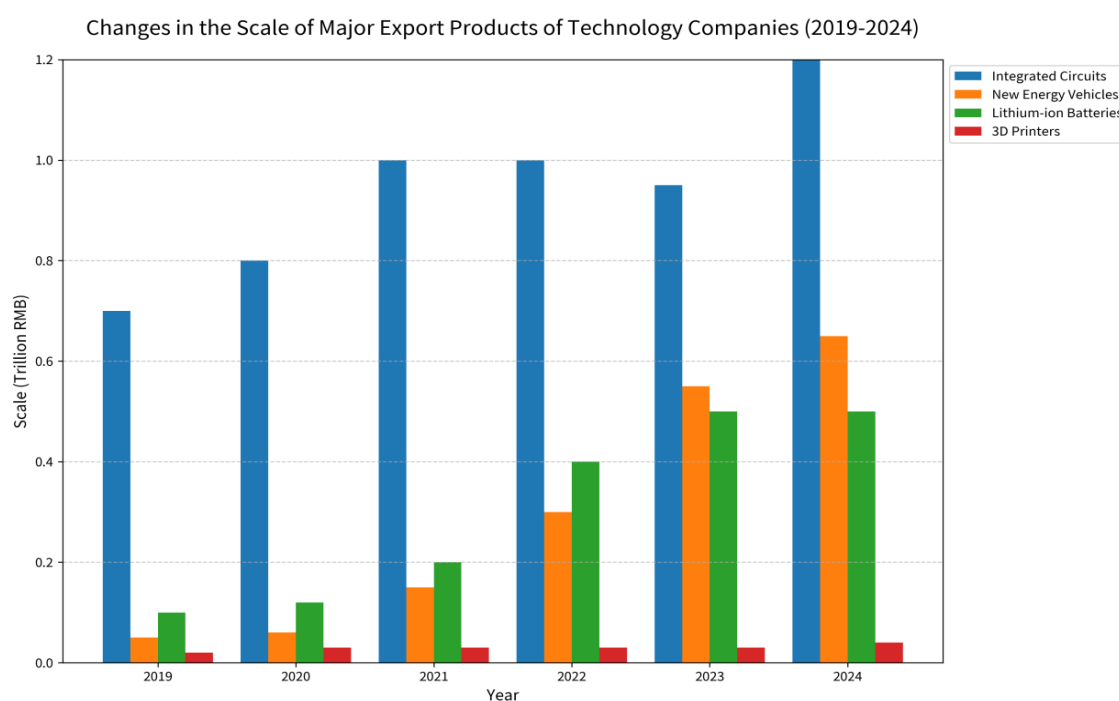
Figure 1 shows the trend chart of major export products of technology enterprises from 2019 to 2024



Data source: General Administration of Customs

It can be seen that in recent years, new energy vehicles have witnessed explosive growth. From 2021 to 2023, the growth rate has exceeded 80% for three consecutive years. In 2023, the export value (547.6 billion yuan) increased by 8.2 times compared to 2019 (59.6 billion yuan). The growth rate of lithium batteries has slowed down, with the first negative growth in 2024 (-3.6%), mainly due to the new EU battery regulations (carbon footprint traceability requirements). The integrated circuit market experienced significant fluctuations. In 2023, it dropped by 5.1% due to the chip ban, but resumed growth in 2024 (+18.5%), reflecting the effectiveness of domestic substitution. In 2021, the export of new energy vehicles exceeded 100 billion yuan (157.6 billion yuan), with a year-on-year growth of 129.6%. In 2022, the export value of lithium batteries (383 billion yuan) surpassed that of integrated circuits to become the largest category (accounting for 37.8%). In 2023, the annual increase in new energy vehicles (246.5 billion yuan) exceeded the total export volume of 2019. For specific data, please refer to Figure 2.

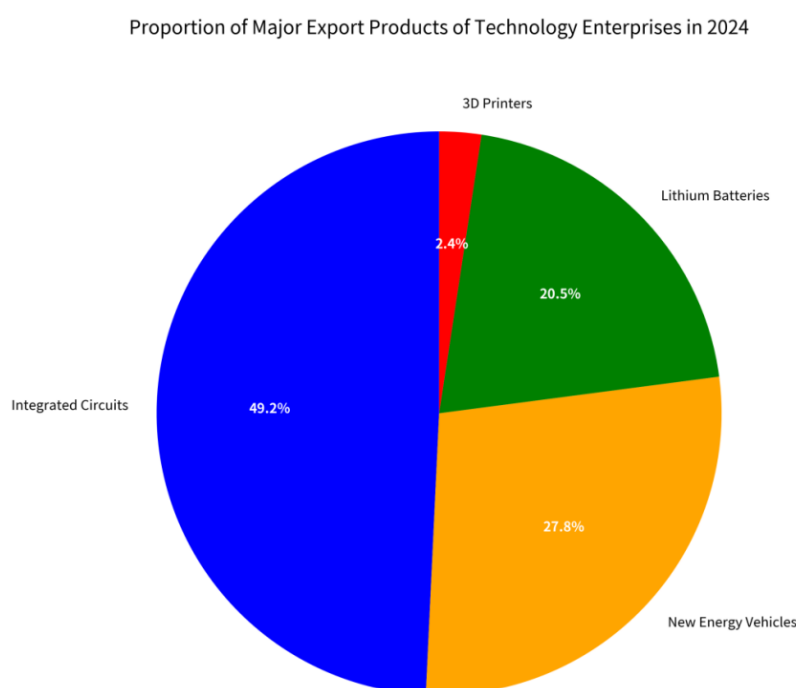
Figure 2 shows the changes in the scale of major export products of technology enterprises from 2019 to 2024



Data source: General Administration of Customs

In 2024, the structure of the main export products of technology enterprises will show a distinct hierarchical distribution feature. Among them, integrated circuits hold the top position with an absolute advantage of 49.2%, fully demonstrating China's global competitiveness in the field of semiconductor manufacturing. The export share of new energy vehicles reached 27.8%, making it the second largest export category. This data confirms the rapid rise of China's new energy vehicle industry in the international market. Lithium batteries, as core supporting products for new energy vehicles, contributed 20.5% of the export share. Together, they accounted for nearly 50%, highlighting that the new energy industry chain has become an important growth pole for China's technology exports. 3D printers accounted for 2.4% of exports. For the specific proportion chart, please refer to Figure 3.

*Figure 3 shows the proportion of major products exported by technology enterprises in 2024*



Data source: General Administration of Customs

### 2.1.2 Market Competition

The global competition pattern in technology trade is becoming increasingly fierce. The competition among countries has escalated from a simple market contest to an all-round competition over technical standards and control of the industrial chain<sup>[4]</sup>. This process presents three notable features.

First of all, trade protectionism gives rise to a new industrial ecosystem. European and American countries are building a “technology alliance” and implementing “precise decoupling” from China through mechanisms such as the Chips and Science Act. Take the semiconductor industry as an example. The United States not only raised the tariff rate for companies like Huawei to 25%, but also joined hands with the Netherlands to restrict the export of EUV lithography machines, which led to a year-on-year decline in China's semiconductor equipment imports in the first half of 2025. This reverse push mechanism has prompted Chinese enterprises to innovate their supply chain models: CATL is building a 100GWh battery factory in Hungary and adopting a “modular whole-plant output” solution. Xiaomi has formed a joint venture with local Vietnamese enterprises, achieving a 60% localization rate for its smartphones and successfully circumventing the EU's carbon border tax<sup>[5]</sup>.

Secondly, the speed of technological iteration is growing exponentially. The training cost of large AI models has plummeted from 4.6 million US dollars in 2020 to 820,000 US dollars in 2025 (OpenAI data), forcing enterprises to restructure their production systems. The “Lighthouse Production Line” deployed at Foxconn's Zhengzhou factory has reduced the assembly time for iPhones to 18 minutes per unit and increased the yield rate to 99.8%. Longi Green Energy has reduced the cost of

photovoltaic modules to \$0.21 per watt through HJT cell technology, a 57% decrease compared to 2020. This efficiency revolution has led to a “winner-takes-all” phenomenon in the industry<sup>[6]</sup>.

Finally, the global industrial chain is evolving in a “dual-track” manner. In the field of consumer electronics, a ternary structure of “Chinese brands + manufacturing in emerging markets + R&D in Europe and America” has been formed. Transsion Holdings’ factory in Ethiopia has achieved an average daily production capacity of 30,000 units, and the local R&D center it has built employs over 200 African engineers. In strategic fields such as aerospace, a “parallel system” has emerged. The Commercial Aircraft Corporation of China’s C919 has obtained airworthiness certifications for Southeast Asia, the Middle East and other regions, directly competing with the Airbus A320neo. This differentiation has led to a new form of technology trade - from January to July 2025, China’s technology licensing revenue from “Belt and Road” countries increased year-on-year, exceeding the growth rate of traditional markets<sup>[7]</sup>.

### 2.1.3 Customer Requirements

With the continuous upgrading of consumer demands, the international market’s requirements for technological products are also evolving towards diversification and personalization. Customers have increasingly higher demands for product performance, quality, service and other aspects. At present, the global demand for technology products shows significant regional differentiation and vertical segmentation characteristics, driving technology enterprises to transform from standardized production to flexible and customized supply chains. The differentiated demands in regional markets have surged. In the field of new energy vehicles, the European and American markets pay more attention to intelligent driving functions (the penetration rate of L2+ level autonomous driving has reached 42%). The Southeast Asian market focuses on cost performance (micro electric vehicles priced under \$20,000 account for 65%). The Latin American market has a unique preference for plug-in hybrid models (for example, BYD’s Song PLUS DM-i in Mexico accounts for 58%). The Middle East market has special requirements for battery thermal management systems due to its hot climate. In the consumer electronics sector, the African market prefers large-capacity battery mobile phones (for instance, the Transsion TECNO 6000mAh model has the highest market share), while the Nordic market pays more attention to environmental protection attributes (the demand for detachable battery designs has increased by 120% annually)<sup>[8]</sup>.

In the field of medical technology, German medical institutions require CT equipment to integrate 5G remote diagnosis modules. United Imaging has developed a dedicated system for this purpose, which has driven up the export unit price. In terms of educational research, the programming robots purchased by K12 schools in the United States need to be compatible with the Scratch 3.0 teaching system. Ubtech has developed an educational kit specifically for this purpose, and the repurchase rate has increased significantly. In terms of industrial scenarios, factories in Southeast Asia have put forward enhanced requirements for AGV robots to be moisture-proof and dust-proof (IP65 grade). Geek+’s customized solutions have helped them capture a portion of the market share in Vietnam<sup>[9]</sup>.

### 2.1.4 Policy Environment

The Trump administration’s imposition of tariffs and the Federal Reserve’s strategy of raising and lowering interest rates have increased the uncertainty of the entire global trade environment. The adjustment of international trade policies and changes in the economic situation directly affect the development of foreign trade business of technology enterprises. Fluctuations in international trade policies have significantly affected the export strategies of technology enterprises, and under the expectation of tariffs, a “rush to export” effect has emerged. When importing countries (such as the United States) announce plans to impose additional tariffs, export enterprises will rush to ship goods in a concentrated manner before the policy takes effect to avoid future cost increases. In July 2025, China’s integrated circuit exports soared by 29.2%, precisely because the United States plans to impose higher taxes on semiconductors, allowing enterprises to “get a head start” in advance. However, this effect is usually short-term. After the policy is implemented, related exports may decline<sup>[10]</sup>.

Mechanical and electrical products are the backbone of “Made in China”, including mechanical equipment, electronic devices, transportation vehicles, etc. For instance, automobiles (+18.6%) and general machinery (+5.3%), which have made significant contributions, both fall under the category of mechanical and electrical engineering. They have a high technological content and a long industrial chain, and they are the “ballast stones” of China’s exports. Even in the face of

tariff pressure, such advantageous industries can still maintain their competitiveness and support the overall export data. In July 2025, China's trade surplus reached 98.24 billion US dollars, indicating that export earnings were significantly higher than import expenditures. An expansion of trade surplus usually reflects strong external demand or strong competitiveness of domestic industries. However, if it relies on short-term factors such as "grabbing exports" for a long time, it may also mask structural risks, such as excessive reliance on specific markets<sup>[11]</sup>.

## **2.2 Cross-border e-commerce has become a new growth point**

The deep integration of cross-border e-commerce and AI technology is becoming an important engine for technology enterprises to expand their global markets. Through intelligent upgrades, cross-border e-commerce platforms have built efficient and precise global sales networks for technology enterprises. AI technology has deeply permeated the entire chain of cross-border trade. In the product selection stage, intelligent algorithms can analyze global consumption trends in real time. For instance, Amazon's AI product selection tool helps 3C enterprises identify the demand for mini projectors in the Southeast Asian market. In the operation stage, the AI customer service system supports real-time responses in 18 languages, effectively resolving language barriers. Meanwhile, the intelligent logistics system shortens the cross-border delivery time through route optimization. In the marketing stage, AI-generated content accounts for more than half of the total materials for cross-border e-commerce. Drones have increased the conversion rate through personalized video advertisements generated by AI.

The rise of social e-commerce has further accelerated market penetration. Data from TikTokShop shows that the GMV of live-streaming sales of technology companies' products in the Southeast Asian market has grown significantly annually. Dji achieved a single-event sales volume of over 3 million US dollars through local influencer reviews. The intelligence of platforms has significantly lowered the threshold for going global. The AI tools of Alibaba International Station have helped small and medium-sized enterprises reduce the time for listing products from 3 hours to 5 minutes, and Shopee's intelligent translation system has increased the conversion rate of multilingual product pages. With the popularization of innovative applications such as AI digital human anchors and intelligent compliance systems, cross-border e-commerce has made a significant contribution to the overseas revenue of technology enterprises<sup>[12]</sup>.

## **3.Problems Existing in the Digital Transformation Process of Foreign Trade Business of Technology Enterprises Empowered by Technology**

### **3.1 Data silos and system isolation**

During the digital transformation of foreign trade business of technology enterprises, the problems of data silos and system fragmentation have become increasingly prominent, becoming the key bottlenecks restricting the improvement of enterprise operational efficiency. At present, most enterprises have deployed multiple independent management systems such as ERP, CRM, SCM, and WMS. These systems often adopt different technical architectures and database standards, and lack effective integration interfaces, resulting in the formation of numerous data silos within the enterprises. In the context of foreign trade business scenarios, this fragmented system situation has seriously affected the efficiency of cross-departmental collaboration. For instance, the customer order information entered by the sales department in the CRM system cannot be synchronized in real time to the ERP system of the production department. The logistics team needs to obtain freight data from another independent platform, while the finance department has to manually verify the report data from multiple systems during the final settlement. This fragmented data management approach not only leads to a large amount of repetitive work but also results in low overall operational efficiency of the enterprise<sup>[13]</sup>.

### **3.2 The application of technology is disconnected from demand**

In the process of promoting the digital transformation of foreign trade business by technology enterprises, there is a widespread phenomenon where the application of technology is seriously disconnected from actual demands. Many enterprises fall into the trap of blindly pursuing technological innovation. Without fully assessing their business needs, they hastily introduce cutting-edge technologies such as AI and blockchain, which ultimately leads to a low input-output ratio and even a regression in business efficiency. The essence of this issue lies in the fact that business decision-makers' understanding of new technologies remains at the conceptual level, lacking in-depth consideration of the applicable scenarios



and implementation conditions of the technologies<sup>[14]</sup>.

### 3.3 Barriers to Cross-border Payment and Settlement

Against the backdrop of the rapid development of global digital trade, cross-border payment and settlement issues have increasingly become the key bottleneck restricting the development of foreign trade business of technology enterprises. The traditional bank telegraphic transfer system remains the mainstream channel for cross-border payments at present, but its inherent structural flaws impose a significant burden on enterprises. On the one hand, the wire transfer fee remains high, and the comprehensive cost of a single transaction usually reaches 1% to 3% of the transaction amount, which is particularly unfavorable for technology-based small and medium-sized enterprises that frequently conduct small transactions. For instance, a certain smart hardware export enterprise has over 1,200 transactions annually, and its handling fee expenses alone account for 8.5% of its net profit. On the other hand, the period for funds to arrive is long, generally taking 3 to 5 working days. If multiple levels of bank transfers are involved, it may even be extended to more than 7 days<sup>[15]</sup>.

### 3.4 Cybersecurity and Compliance Risks

In the digital transformation process of foreign trade business of technology enterprises, cybersecurity and data compliance risks have risen to become strategic issues affecting the international competitiveness of enterprises. With the continuous improvement of the global data regulatory system and the continuous upgrading of cyber attack methods, enterprises are facing unprecedented challenges in data security management. These risks not only threaten the security of business secrets but may also lead to huge compliance penalties and market access restrictions. In addition, data security threats present diversified and complex characteristics. Sensitive information such as customer data, transaction records, and technical documents that circulate in foreign trade business scenarios is becoming a key target for hacker attacks. Attackers can exploit the API interface vulnerabilities of third-party logistics systems to steal transaction records of customers' credit card information, causing direct economic losses<sup>[16]</sup>.

## 4. Countermeasures and Suggestions

### 4.1 Build a platform to connect data, break down silos and promote collaboration

To solve the key problem of data silos that restricts the digital transformation of enterprises, it is necessary to build a comprehensive solution covering technical architecture, management mechanisms and talent cultivation.

At the technical implementation level, enterprises should give priority to deploying middleware technologies such as ESB (Enterprise Service Bus) or API gateways. By building a unified data middle platform, they can achieve seamless integration of core business systems such as ERP, CRM, and SCM. This technical architecture not only breaks down the data barriers among various systems but also provides standardized data interfaces to ensure the real-time flow of information among different departments. In terms of the management system, enterprises need to establish a complete cross-departmental data sharing mechanism. First of all, it is necessary to formulate unified data standard norms, clearly define data formats, field definitions and transmission protocols, laying the foundation for system interconnection. Secondly, a data governance committee should be established, directly led by the senior management, to clearly define the data management responsibilities and authority boundaries of each department. At the same time, it is also necessary to establish a corresponding performance appraisal system, incorporating the timeliness and accuracy of data sharing into the department's KPI assessment system. At the tool application level, enterprises can introduce advanced technological means such as RPA (Robotic Process Automation) and intelligent data cleaning. RPA robots can work continuously for 7×24 hours, automatically completing tasks such as data collection, format conversion, and system entry that originally required manual operation. To implement these transformation measures, enterprises also need to attach importance to the cultivation and introduction of digital talents. On the one hand, systematic training should be provided to the existing employees to enhance their data thinking and system operation capabilities. On the other hand, it is necessary to introduce compound talents who are proficient in both business and technology to form a professional digital transformation team<sup>[17]</sup>.

Only through this systematic reform that integrates technology, management and talent can enterprises truly break free from the shackles of data silos and build an agile and efficient digital operation system. When order information can be synchronized in real time to the production department, inventory data can be automatically updated to the logistics system,

and financial statements can be generated with one click, enterprises have achieved a qualitative leap from traditional “passive response” to modern “intelligent collaboration”. This not only significantly enhances operational efficiency and reduces labor costs, but also helps enterprises quickly seize market opportunities and gain a competitive edge in the uncertain international trade environment<sup>[18]</sup>.

#### **4.2 Re-examine demands and verify scenarios, strengthen implementation and enhance effectiveness**

In response to the issue of excessive commitment by technology suppliers, enterprises should establish strict technology assessment and verification mechanisms. First, a joint assessment team composed of IT experts, business backbones and third-party consultants should be formed to verify each functional point promised by the supplier one by one. A three-stage implementation strategy of “proof of Concept (POC) → small-scale pilot → full-scale promotion” can be adopted. Secondly, clearly stipulate the key performance indicators (KPIs) and breach of contract clauses in the contract. For instance, it should be stipulated that the multi-language recognition accuracy rate of the intelligent customer service system must not be lower than 90%; otherwise, the service fees will be refunded proportionally. In addition, enterprises should also establish a blacklist system for suppliers and impose a one-vote veto on suppliers with records of false advertising<sup>[19]</sup>.

In response to the weak digital foundation of enterprises, it is suggested to adopt a transformation strategy of “consolidating the foundation and proceeding step by step”. The primary task is to build a unified data governance system, including formulating enterprise-level data standards, establishing a master data management system (MDM), and implementing a data quality monitoring mechanism. Secondly, adopt a technical architecture of “thick platform, thin application”, first achieve system integration through ESB or data middle platform, and then gradually add intelligent applications. In addition, it is suggested that a digital transformation maturity assessment system be established to diagnose the organization, processes, technology and other dimensions every quarter to ensure that the transformation pace matches the actual capabilities of the enterprise.

#### **4.3 Expand channels, optimize settlement, reduce costs and shorten cycles**

First of all, make good use of the innovative tools permitted by regulatory policies. Cross-border RMB settlement can avoid exchange rate risks and has been widely accepted in regions such as ASEAN and the Middle East. Meanwhile, free trade accounts (FT accounts) can also offer more convenient cross-border fund transfer services. In addition, choose a professional cross-border payment service provider. In light of the characteristics of different regional markets, traditional banks, third-party payments and localized solutions are combined and used. Secondly, leverage financial technology to achieve intelligent fund management. Through API interfaces, multiple national bank accounts, payment platforms and ERP systems are directly connected to achieve real-time visualization and automatic allocation of global capital flows. Finally, actively participate in policy communication and innovation pilot projects. Reflect the actual demands of enterprises through channels such as industry associations and strive to participate in the pilot program for facilitating cross-border payments.

With the in-depth development of the digital economy, the cross-border payment sector is undergoing profound changes. If enterprises can proactively adapt to this trend and break through payment barriers through technological innovation and strategic optimization, they will not only enhance their own capital operation efficiency but also gain a key advantage in global competition<sup>[20]</sup>.

#### **4.4 Build a defense line to ensure compliance, control risks and protect data**

Building a comprehensive network security and compliance management system has become an essential condition for technology enterprises to conduct international business. At the technical protection level, a “defense in depth” strategy should be implemented. New-generation firewalls (NGFW) and intrusion prevention systems (IPS) should be deployed at the network boundary. Zero-trust architecture (ZTNA) should be enabled for the cloud environment, and advanced protection technologies such as homomorphic encryption should be adopted for core data. Some semiconductor enterprises have successfully increased the interception rate of network attack attempts through this multi-layer protection system. At the level of compliance management, a “trinity” compliance framework should be established. A Data Protection Office composed of legal affairs, IT and business departments should be set up. Compliance processes covering the entire data life cycle should be formulated, and regular compliance audits and training should be implemented. Some biometric technology enterprises have

increased their compliance rate with GDPR through this framework.

## 5. Conclusion

First of all, the success of digital transformation cannot be achieved without clear strategic planning and goal setting. Therefore, technology enterprises need to formulate a clear digital transformation strategy based on their own development stage and resource holding status to ensure a clear direction and reasonable allocation of resources during the transformation process. Secondly, the digital capabilities of employees are an important foundation for technology enterprises to achieve digital transformation. Therefore, enterprises need to continuously enhance the digital skills of their employees to help them adapt to new working models and tools. Thirdly, technology platforms and system integration are key elements in the digital transformation of technology enterprises, which will directly affect the construction and application effect of the enterprise's digital capabilities. Finally, collaborative innovation with external partners. Through cooperation with technology providers, advanced digital solutions and technical support can be obtained to make up for the insufficiency of the enterprise's internal technical capabilities. Cooperation with research institutions can provide enterprises with cutting-edge technological research and development support, thereby promoting breakthroughs in digital innovation for enterprises. Customers and supply chain partners are also important partners in the digital transformation of enterprises. Through interaction and cooperation with customers, enterprises can better understand customer needs, thereby optimizing the digital experience of products and services. Cooperation with supply chain partners helps enterprises connect upstream and downstream links, build a more agile and efficient supply chain system, and thereby improve overall operational efficiency. The cooperative approach of collaborative innovation not only helps enterprises enhance their technological level and innovation capacity, but also reduces the costs and risks of enterprises in digital transformation to the greatest extent through resource sharing, risk sharing and other means, forming a digital ecosystem, thereby assisting enterprises in achieving comprehensive digital transformation. In conclusion, the digital transformation of technology enterprises has become a strategic measure to promote high-quality development of enterprises and enhance their market competitiveness. Therefore, in the process of digital infrastructure construction, business process reengineering, organizational structure and management model adjustment, as well as the implementation of data-driven decision-making, technology enterprises need to comprehensively consider various diversified factors, formulate practical and feasible implementation paths and strategies, and thereby achieve effective digital transformation.

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## Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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# Research on the Path of Integrating Industry and Education to Improve the Career Development Ability of College Students with the Help of Artificial Intelligence

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**Abstract:** Against the backdrop of deep integration between the digital economy and educational reform, artificial intelligence (AI) technology has opened up new possibilities for enhancing the quality and efficiency of industry-education integration. This paper focuses on the core needs of college students' career development capabilities, exploring the inherent logic and practical pathways for AI-powered industry-education integration. By analyzing current challenges in resource alignment, teaching adaptation, and evaluation feedback within industry-education integration, the study proposes key solutions from a technology-enabled perspective: establishing intelligent supply-demand matching platforms, developing personalized training systems, and creating dynamic evaluation mechanisms. The research aims to bridge the gap between industrial demands and educational resources through AI technology, achieving precise resource alignment, collaborative teaching process optimization, and targeted vocational skill cultivation. These efforts provide theoretical references and practical guidance for enhancing college students' employability and promoting deeper integration between education and industrial chains.

**Keywords:** Artificial Intelligence; Industry-Education Integration; Career Development Capabilities; Empowerment Pathways

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## 1.Introduction

The digital economy is accelerating industrial restructuring while raising the bar for talent's knowledge, skills, and competencies. Yet higher education remains disconnected from industry needs, creating a glaring disconnect between graduates' "employment woes" and employers' "labor shortages". While industry-education integration serves as a crucial solution, traditional models face challenges like mismatched resource allocation, outdated curricula, and rigid evaluation systems that fail to meet evolving industry demands. Artificial intelligence, with its strengths in data processing and intelligent matching, injects new momentum into enhancing the effectiveness of industry-education integration. Exploring how AI can empower this integration to boost graduates' career development capabilities now holds significant theoretical and practical value.

While domestic scholars have conducted research on innovation in industry-education integration models and technological applications, systematic exploration of how artificial intelligence enhances vocational development capabilities for college students remains insufficient.<sup>[1]</sup> Meanwhile, existing mature industry-education integration models and technological

applications from overseas, due to differences in educational systems and industrial contexts, lack adaptability to China's national conditions. This study will define core concepts, analyze challenges in industry-education integration, and examine three key dimensions: resource alignment, instructional implementation, and evaluation feedback mechanisms.

The research constructs the empowerment path and proposes the implementation guarantee, and adopts the literature research method, case analysis method and logical analysis method to ensure the rigor of the research.

## **2.Key Conceptual Definitions and Theoretical Support for Industry-Education Integration**

Artificial intelligence (AI) is an emerging technological discipline dedicated to researching, developing, and applying theories, methodologies, and systems that simulate, extend, and enhance human intelligence. Its core technologies encompass machine learning, deep learning, natural language processing, and computer vision, enabling intelligent data analysis, pattern recognition, and autonomous decision-making. In education, AI applications manifest through smart teaching systems, resource matching, personalized guidance, and educational assessment, providing robust technical support for educational innovation. Industry-education integration refers to an educational model characterized by deep collaboration between education and industry. Its core objective is to break down barriers between academia and industry by integrating resources from universities, enterprises, and government agencies. This approach incorporates industrial demands throughout the entire talent development process,<sup>[2]</sup> achieving organic integration of teaching with production practices and scientific innovation. The essence of industry-education integration lies in cultivating talent through coordinated efforts between education and industry, thereby enhancing the quality of talent development and meeting the industry's demand for high-caliber professionals. College students' career development capabilities encompass comprehensive competencies that enable them to adapt to occupational requirements, achieve career goals, and promote sustainable career progression during their professional development journey. The core elements of these capabilities include professional skills encompass specialized knowledge and technical competencies relevant to one's field of study, forming the foundation for specific career paths. General competencies include communication, teamwork, problem-solving, and innovative learning abilities, which are crucial for adapting to diverse professional environments. Professional ethics, work ethic, and a strong sense of responsibility constitute the core values that ensure sustainable career development.

The collaborative education theory originates from synergetics, emphasizing that different entities achieve resource sharing and complementary advantages through mutual cooperation and coordination, ultimately maximizing overall benefits. In industry-education integration, universities, enterprises, and governments act as distinct educational units. Through collaborative efforts, they organically integrate educational resources with industrial resources to form a synergistic educational force. Artificial intelligence technology provides efficient communication platforms and resource integration tools for collaborative education, facilitating information sharing and coordinated interaction among stakeholders to enhance educational outcomes. The personalized learning theory focuses on student-centered approaches, tailoring learning content, methods, and support based on individual differences such as learning interests, abilities, and career planning. By analyzing students' learning data and career orientation data, AI technology can accurately identify individual characteristics and developmental needs, enabling customized learning plans and practical training programs. This approach achieves personalized education, significantly improving the relevance and effectiveness of students' career development capabilities. The demand-oriented theory posits that educational activities should revolve around societal and market demands, with the core objective of meeting the talent needs for social development. In industry-education integration, industrial demands serve as the fundamental guide for talent cultivation. Universities should promptly adjust their talent development programs, teaching content, and practical training projects in response to evolving industrial requirements. Artificial intelligence technology can capture real-time industry trends and talent demand information, providing data-driven support for optimizing university talent cultivation. This ensures precise alignment between talent development and industrial needs.

## **3.The Current Difficulties in Integrating Production and Education to Improve the Vocational Development Ability of College Students**



The current integration of production and education promotes the career development ability of college students.<sup>[3]</sup> The advancement process still faces multiple pressing challenges requiring resolution. In terms of resource integration, university-enterprise collaboration remains confined to traditional models like signing agreements and periodic offline meetings. The absence of efficient sharing platforms and intelligent matching mechanisms for real-time supply-demand information has resulted in universities' significant lag in understanding evolving industry talent needs and technological trends. Consequently, their talent development plans often fail to align with actual industrial demands. Meanwhile, enterprises' advanced technologies, frontline practitioners, and other premium resources struggle to be effectively incorporated into academic curricula due to lack of standardized conversion pathways. Furthermore, the absence of unified matching criteria between supply and demand makes it difficult for universities to identify complementary cooperation directions based on their strengths, while enterprises face challenges in finding compatible partner institutions. This ultimately leads to underutilization of industry-education resources and inefficient supply-demand matching. In terms of teaching adaptation, the pace of curriculum updates in higher education institutions lags significantly behind industrial technological advancements. Academic content predominantly focuses on traditional theoretical knowledge, failing to incorporate emerging technologies, processes, and methodologies from real-world production. This disconnect between classroom learning and practical workplace scenarios results in deficiencies in vocational skill development. The teaching approach remains heavily lecture-based, with limited practical training that primarily involves simulated campus exercises. The absence of authentic industrial environments and comprehensive job experience hinders effective cultivation of students' hands-on abilities and problem-solving skills. Moreover, faculty members predominantly hold academic backgrounds rather than frontline industry experience, making it challenging to achieve deep integration of theory and practice. This further undermines the educational quality's role in supporting vocational competency development. Regarding evaluation mechanisms, talent assessment remains institution-dominated with overly simplistic metrics. Excessive focus on theoretical exam scores and in-house training reports overlooks core industry demands such as vocational proficiency, professional ethics, and workplace adaptability. Evaluation methods predominantly rely on summative assessments like final exams and training completion reports, which fail to track students' skill progression dynamically. Inadequate feedback mechanisms prevent institutions from promptly incorporating employer evaluations of graduates' performance to adjust training programs. Meanwhile, enterprises show low participation enthusiasm due to insufficient channels and incentive mechanisms, leading to evaluation results that fail to objectively reflect industry's genuine talent needs. In terms of multi-party collaboration, the synergy among universities, enterprises, and government remains notably insufficient. Universities, constrained by limited educational resources and administrative systems, struggle to fully motivate enterprises to engage deeply. Some companies lack sufficient understanding of the long-term value of industry-education integration, viewing participation as costly with no immediate returns, leading to low willingness to collaborate. While the government has introduced supportive policies, the lack of detailed implementation guidelines and effective supervision mechanisms hinders policy benefits from being fully realized. This creates challenges in forming stable and efficient collaborative talent development mechanisms among all stakeholders. These difficulties overlap with each other, which restrict the systematic improvement of college students' career development ability.

#### **4. Constructing Pathways for AI-Enabled Industry-Education Integration to Enhance Vocational Development Capabilities of College Students**

Amid the dual drivers of digital economy reshaping industrial structures and accelerating educational reforms, artificial intelligence (AI) technologies—encompassing data mining, deep learning, and intelligent collaboration—are emerging as pivotal forces to dismantle barriers in traditional industry-education integration and redefine talent development models. While conventional industry-education partnerships aim to bridge educational resources with industrial needs, they often face practical challenges: inefficient resource coordination due to information asymmetry, mismatched curricula that fail to meet industry demands, and delayed competency feedback from rigid evaluation systems. These limitations not only hinder the core objective of enhancing students' career readiness but also fall short of addressing the digital economy's urgent need for versatile professionals with cross-disciplinary expertise.

The deep integration of artificial intelligence technology with industry-education collaboration provides a systematic solution to address these challenges. From the perspective of resource alignment, AI-powered platforms for industry-education integration can consolidate educational resources such as university program offerings, talent development plans, and practical training facilities, industrial resources including corporate trends, job market standards, and R&D directions, along with policy resources like government support and industry regulations. Through big data analysis and intelligent matching algorithms, these platforms achieve precise supply-demand matching between academia and industry. This system not only provides universities with real-time industry demand data to optimize talent cultivation programs, but also recommends qualified university resources and potential talents to enterprises. Additionally, it matches students with career-aligned practical training and employment opportunities, effectively breaking down information barriers between the “education sector” and “industry sector” to create a virtuous ecosystem of efficient resource circulation.

In optimizing talent development processes, AI-powered personalized training systems have revolutionized practical education. Virtual simulation training bases utilizing VR, AR, and digital twin technologies faithfully recreate corporate production environments, process workflows, and operational standards, enabling students to enhance professional skills in secure, repeatable immersive environments. Through multidimensional analysis of learning behavior data, career aptitude assessments, and competency gaps, machine learning algorithms generate customized training plans that precisely match content, methods, duration, and job roles. These adaptive systems dynamically adjust training feedback, achieving true “tailored education” that addresses the limitations of traditional “one-size-fits-all” approaches. Furthermore, AI-driven platforms for faculty collaboration and professional development facilitate university instructors’ engagement in corporate R&D, attract industry experts to deliver practical courses, strengthen dual-qualified faculty teams, and promote seamless integration of theoretical instruction with industrial practice.

From the perspective of quality assurance mechanism, the dynamic evaluation system empowered by artificial intelligence has innovated the talent assessment model.<sup>[4]</sup> A multidimensional evaluation framework, centered on industry job requirements and students’ career development capabilities (covering professional skills, general competencies, and vocational literacy), integrates real-time data collection and big data analysis from artificial intelligence to assess students’ learning progress, practical training, and workplace performance. This approach enables comprehensive and objective evaluation of students’ abilities through the combination of formative and summative assessments, dynamically tracking skill development while accurately measuring educational outcomes, thus avoiding the one-sidedness of traditional summative evaluations. The synchronized feedback of evaluation results to universities, students, and enterprises not only provides a basis for optimizing training programs, formulating skill enhancement plans for students, and adjusting recruitment strategies for companies, but also enhances the guiding and motivational role of evaluations by linking results to student rewards/punishments and faculty assessments, ensuring continuous improvement in talent cultivation quality.

Furthermore, the AI-powered collaborative management platform integrates project management, resource allocation, and progress monitoring functions, enabling efficient communication and coordination among universities, enterprises, and government entities in industry-education integration. Through fiscal subsidies and tax incentives, the government encourages deeper corporate participation while linking integration outcomes with university resource distribution to boost institutional engagement. By leveraging industry associations and AI-driven industrial demand analysis with standard-setting support, the platform further strengthens the safeguard mechanism for industry-education integration, driving deep alignment across the “education chain - talent chain - industrial chain - innovation chain”.

## **5.Implementation Guarantee of Artificial Intelligence Enabling Industry-Education Integration**

The government should strengthen the top-level design of policies, introduce targeted policies and measures, provide policy support for the integration of industry and education with artificial intelligence, and formulate people

The specialized policy for applying artificial intelligence in education clearly defines the development goals, key tasks, and safeguard measures for AI-powered industry-education integration. It increases fiscal investment, establishes special funds, and supports R&D and application of AI technologies in industry-education integration, such as intelligent platform

construction and virtual training base development. The policy also improves relevant laws and regulations to standardize AI applications in education, protect student privacy and data security, while strengthening policy promotion and implementation supervision to ensure effective implementation of measures. This comprehensive approach fully leverages the guiding and supportive role of policies.

Strengthen R&D and application of artificial intelligence (AI) technologies in industry- education integration to enhance technical support capabilities. Encourage collaboration between universities, research institutions, and enterprises in AI technology development, with a focus on breakthroughs in core technologies such as intelligent matching algorithms, virtual simulation techniques, and big data analytics. This will provide advanced technical support for industry-education integration. Cultivate interdisciplinary talents proficient in both AI technology and education-industry integration to ensure talent security for AI-powered industry- education collaboration. Simultaneously, establish a technical service system offering AI technology consulting, training, and maintenance services to universities and enterprises, ensuring smooth implementation of technological applications.

Establish a diversified funding mechanism to provide adequate financial support for AI- powered industry-education integration. In addition to government fiscal investments, enterprises should be encouraged to increase funding for industry-education collaboration. Through school-enterprise partnerships in establishing training bases and R&D centers, shared capital and risk-sharing mechanisms can be achieved. Social capital should be guided to participate in industry-education integration via industrial investment funds and crowdfunding. Funding channels should be diversified while strengthening fund management and supervision to enhance efficiency. This ensures that resources are allocated to critical areas including AI technology R&D, platform development, and faculty training.

To strengthen the cultivation of interdisciplinary talents and provide talent support for AI- powered industry-education integration, universities should adjust their academic programs by adding majors related to artificial intelligence, big data, and digital economy. This will foster professionals with expertise in AI technology, education, and industrial knowledge. Institutions should also enhance faculty training to improve teachers' AI application skills and industry- education integration capabilities. Meanwhile, enterprises need to strengthen the development and recruitment of technical talents, upgrade their technical service capabilities for industry- education collaboration, and establish talent mobility mechanisms. By promoting talent exchanges and sharing among universities, enterprises, and research institutions, we can fully leverage the synergistic effects of human resources.

## 6. Conclusions and Outlook

This study explores pathways for enhancing vocational development capabilities of college students through AI-powered industry-education integration. By defining core concepts and analyzing theoretical foundations, it systematically examines current challenges in this integration and proposes corresponding solutions. Key conclusions include: First, existing industry-education integration faces practical obstacles such as imprecise resource alignment, inadequate teaching adaptability, rigid evaluation feedback mechanisms, and insufficient multi- party collaboration, which significantly hinder both integration effectiveness and student career development. Second, AI technology inherently aligns with industry-education integration, providing technical support for quality improvement. Based on collaborative education theory, personalized learning theory, and demand-oriented theory, the study constructs AI-enhanced pathways across four dimensions: resource alignment, teaching implementation, evaluation feedback, and multi-party collaboration. These pathways—encompassing intelligent supply-demand matching platforms, personalized training systems, dynamic evaluation mechanisms, and improved collaborative frameworks—effectively address traditional integration challenges. Finally, ensuring smooth implementation requires comprehensive support across four dimensions: policy, technology, funding, and talent. This holistic support system will drive deeper AI- powered industry-education integration and elevate vocational development capabilities for college students.

This study establishes a framework for enhancing vocational development capabilities of college students through AI-powered industry-education integration. However, certain limitations remain. Future research could focus on the following areas: 1) Content refinement: Develop tailored implementation strategies by analyzing specific pathways for

AI-enhanced integration across different academic disciplines and university types, aligning with industry demands. 2) Practical application: Strengthen collaboration between universities and enterprises through pilot programs, systematically documenting lessons learned to continuously optimize the framework and accelerate the commercialization of research outcomes. As AI technology advances and industry-education integration deepens, its applications will expand significantly. This integration holds promise for achieving deep synergies between education and industry in talent cultivation, ultimately enhancing students' career development capabilities and promoting. To make greater contribution to the high-quality development of higher education and the transformation and upgrading of industry.<sup>[5]</sup>

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## Conflict of Interests

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# Localization Exploration of the German Dual-system Model under the Background of Vocational Education Reform: Taking the New Energy Vehicle Technology Major of K College in Jiangxi Province as an Example

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**Abstract:** Driven by the global energy structure transformation and the “dual-carbon” strategy, China’s new energy vehicle industry has experienced explosive growth, posing new challenges to the supply of technical and skilled talents. The traditional vocational education model faces problems such as lagging curricula, insufficient practical training, and disconnection between schools and enterprises. The German dual-system vocational education system is renowned for its unique training model and high employment rate, which is of great significance for the development of the new energy vehicle technology major in Chinese higher vocational education. This paper analyzes the characteristics of the German dual-system model, combines it with the actual situation of Chinese vocational education, and explores its localization application and innovation. The research shows that by deepening school-enterprise cooperation, optimizing curriculum settings, strengthening practical teaching, building a “double-qualified” teaching team, improving the assessment system, seeking policy support, and promoting international exchanges, the education quality and employment rate of this major can be effectively improved, and more high-quality technical and skilled talents can be cultivated for the new energy vehicle industry.

**Keywords:** Vocational Education; New Energy Vehicle Technology; German Dual-system; Localization

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## 1.Introduction

With the rapid development of China’s economy and the transformation and upgrading of the industrial structure, vocational education has become increasingly prominent in the national strategy<sup>[1]</sup>. In recent years, the government has successively introduced policies such as the “Implementation Plan for the Reform of National Vocational Education” and the “Opinions on Promoting the High-quality Development of Modern Vocational Education” to promote vocational education reform and improve the quality of talent cultivation. Germany’s manufacturing industry ranks among the world’s top in terms of development level. It rapidly cultivates professional and technical talents through the dual-system vocational education model, which is widely recognized as an advanced example of vocational education globally<sup>[2]</sup>. Against this background, the German dual-system vocational education model, with its high employment rate and practice-oriented teaching

characteristics, has become an important reference for China's vocational education reform<sup>[3]</sup>. As a national strategic emerging industry, the new energy vehicle industry has an increasingly urgent demand for high-quality technical and skilled talents. However, there are still problems in the current talent cultivation of this major, such as insufficient in-depth school-enterprise cooperation, lagging curriculum settings, and insufficient practical teaching. Therefore, exploring the localization application and innovation of the German dual-system model is of great significance for improving the education quality and employment rate of the new energy vehicle technology major<sup>[4]</sup>.

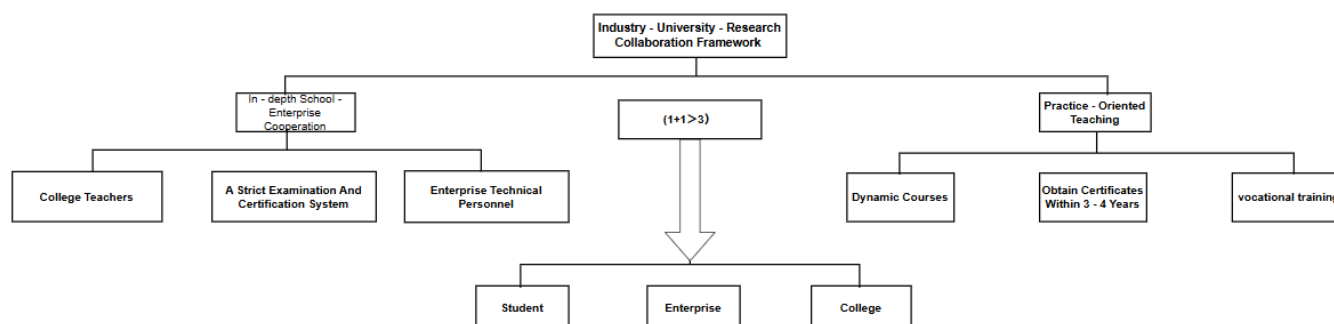
## 2.The Connotation of the German Dual-system Vocational Education Model

Different from the traditional education model, the German dual-system is basically positioned to cultivate high-quality technical and skilled talents (applied talents)<sup>[5]</sup> who meet market demands. In the context of the rapid development of globalization and technological innovation and the ever-changing demands of the labor market, such talents have significant advantages in market competition, can distinguish themselves from ordinary labor forces, and stand out. Its advantages are mainly reflected in three aspects:

### 2.1 In-depth School-enterprise Cooperation and the Construction of a “Double-qualified” Teaching Team

The core of the German dual-system is the close cooperation between enterprises and schools. Enterprises are not only the demand side of education but also the provider of education<sup>[6]</sup>. The teaching team consists of school teachers and enterprise technicians, ensuring the practicality and advancement of teaching content. Through cooperation agreements, enterprises participate in curriculum design, provide internship positions, and dispatch technicians to serve as part-time teachers to ensure that teaching is highly consistent with industry demands. The graduation projects of higher education are jointly set by enterprises and university professors, focusing on the research of actual enterprise problems, realizing the direct transformation of production-learning-research (as shown in the following figure1). Graduation theses are jointly supervised by professors and enterprise supervisors<sup>[7]</sup>. At the same time, relying on a strict assessment and certification system, the quality of education and students' abilities are guaranteed.

Figure1



### 2.2 Practice-oriented Teaching and Curriculum Design Centered on Vocational Needs

The German dual-system emphasizes the cultivation of practical abilities. Students spend a high proportion of time interning in enterprises, during which they receive systematic vocational training, master practical operation skills and problem-solving abilities, and there is a strict assessment and certification system. In the curriculum model of dual-system universities, students can obtain both a university graduation certificate and a vocational training completion certificate in 3-4 years, saving time costs<sup>[7]</sup>. Theoretical courses select materials centered on vocational activities, with a wide range of knowledge, appropriate depth, and strong comprehensiveness, which is conducive to cultivating students' comprehensive analysis and problem-solving abilities. The courses are subdivided by semester, expanding from general to specific and from shallow to deep around the major. The settings are flexible and can be adjusted in a timely manner according to industry changes. Moreover, they are arranged by experts with rich industry experience, paying more attention to direct vocational experience.

### 2.3 The Win-win Cooperation Effect

The cooperation model of the dual-system can achieve an effect of  $1 + 1 > 3$ . In the German dual-system university vocational



education model, enterprises participate in talent cultivation, achieving a win-win situation for themselves, universities, and students<sup>[8]</sup>. Through cooperation, enterprises obtain high-quality skilled reserve talents. Statistics from the University of Duisburg-Essen show that approximately 80% of students stay to work in the signed training companies after graduation<sup>[7]</sup>. Many students can become independent and competent in their jobs in the later stage of vocational training and can start working upon graduation<sup>[9]</sup>. Compared with ordinary fresh graduates, they save a relatively long adaptation period and are familiar with the enterprise environment and culture, which is conducive to cultivating a sense of belonging.

### 3.The Current Situation and Challenges of the New Energy Vehicle Technology Major under the Background of Vocational Education Reform

With the increasingly severe global energy crisis and environmental problems, the new energy vehicle industry has developed rapidly and become an important direction for economic transformation and industrial upgrading in various countries. The new energy vehicle technology major has emerged as the times require, aiming to cultivate high-quality technical and skilled talents to meet the needs of industrial development.

The policy environment has a profound impact on the development of this major. Driven by China's vocational education reform, the new energy vehicle technology major is developing positively, and the employment rate of graduates is rising steadily, which benefits from the country's strong support for the new energy vehicle industry and the strong market demand for related technical talents. The new energy vehicle industry in Jiangxi Province is growing at an impressive rate. As a major base for university cultivation in the country, the province has a large-scale cultivation of technical talents in the new energy industry. However, as an emerging major, its employment situation and development prospects still have uncertainties.

To explore the matching degree between the quality of talent cultivation and industrial demands, this paper conducts a questionnaire survey among 160 students majoring in new energy vehicle technology at K College in Jiangxi Province, focusing on four dimensions: the depth of school-enterprise cooperation, the rationality of curriculum settings, the teaching quality of teachers, and employment competitiveness. The reliability and validity of the survey scale are good (as shown in the following table 1):

Table1

Dimension	Number of Items	Cronbach's $\alpha$	KMO Value
School - enterprise Cooperation	5	0.894	0.965
Curriculum Settings	4	0.839	
Teaching Staff	4	0.819	
Employment Competitiveness	4	0.858	
Total Scale	17	0.958	

Industrial development is a key factor determining the employment rate. With the increase in the market penetration rate of new energy vehicles, enterprises' demand for technical talents continues to grow, providing broad employment space for graduates. However, some factors in the talent cultivation process have affected the employment situation.

#### 3.1 External Influences on Education Quality

Some schools have deficiencies in major settings, curriculum systems, practical teaching, etc., resulting in a gap between the skill levels of graduates and industrial demands. Problems such as weak teaching staff and insufficient training equipment also restrict the improvement of talent cultivation quality. First, school-enterprise cooperation is not in-depth, with shallow cooperation levels and imperfect mechanisms. Second, curriculum settings are lagging, and practical teaching is insufficient. The curriculum content cannot keep up with industrial development, the proportion of practical class hours is low, and students' practical operation and problem-solving abilities need to be improved. Third, there is a lack of a "double-qualified" teaching team, and teachers' practical abilities and industry experience are insufficient.

#### 3.2 Internal Influences of Students' Qualities

In addition to insufficient professional teaching support, some students lack professional awareness and learning motivation, resulting in an unsteady grasp of professional skills and affecting their employment competitiveness. At the same time, some students have biases in their employment concepts, overly pursuing high salaries and stability and being unwilling to start

from grassroots positions, thus missing employment opportunities.

## **4. Enlightenments of the German Dual-system Model on the New Energy Vehicle Technology Major during the Localization Process**

The German dual-system vocational education system is world-famous for its unique training model and high employment rate, and it has important reference significance for the development of the new energy vehicle technology major in China. The following are several enlightenments of the German dual-system vocational education system on this major:

### **4.1 Deepen School-enterprise Cooperation and Strengthen the Construction of a “Double-qualified” Teaching Team**

The new energy vehicle technology major can draw on the German dual-system model to strengthen cooperation with new energy vehicle enterprises and deepen the integration of industry and education. Schools should establish long-term and stable cooperative relationships with enterprises, jointly formulate talent cultivation plans, develop professional courses, and build “factory-in-school” training bases. Through order-based cultivation, modern apprenticeship and other models, seamless connection between talent cultivation and industrial demands can be achieved. Through cooperation agreements, enterprises are enabled to deeply participate in curriculum design, provide internship positions, and dispatch technicians to serve as part-time teachers to ensure that teaching content is in line with industry demands. In terms of teaching staff construction, on the one hand, training and further education should be carried out for existing teachers, and they should be encouraged to take temporary positions in enterprises to improve their professional levels and teaching abilities. On the other hand, enterprise technical backbones should be hired as part-time teachers to bring the latest technologies and management experience into the classroom, and a high-level “double-qualified” teaching team should be built to provide guarantee for cultivating high-quality technical and skilled talents.

### **4.2 Adhere to Practice-orientation and Optimize Curriculum Settings**

The new energy vehicle technology major should increase the proportion of practical teaching, set up more training courses and internship links, arrange students to rotate and intern in new energy vehicle manufacturing plants, maintenance service centers, charging facility operation companies, etc., increase investment in training equipment, and improve students’ practical operation and problem-solving abilities. At the same time, a dynamic curriculum update mechanism should be established, communicate regularly with enterprises, keep up with industrial demands, and adjust the curriculum system according to technological development trends and changes in job requirements. For example, for emerging fields such as battery technology and intelligent networking, relevant courses should be added to update teaching content in a timely manner and cultivate students’ competitiveness in emerging fields.

### **4.3 Improve Career Planning Guidance and Improve the Assessment and Certification System**

Schools should attach importance to students’ career planning and employment guidance, helping students clarify their career goals and development paths. From the beginning of enrollment, students should be guided to understand the industry development trends and employment prospects, and personalized employment guidance services should be provided. A dynamic talent demand database should be established to let students perceive the current workplace situation in advance. A sound employment guidance system should be established to provide students with all-round services such as career planning, job-seeking skills, and psychological counseling.

Vocational quality education should be integrated into the whole process of professional teaching to cultivate students’ professional ethics, teamwork ability, and innovation and entrepreneurship spirit. Students should be encouraged to participate in various skill competitions and innovation and entrepreneurship activities to improve their practical abilities and comprehensive qualities. A strict and complete assessment and certification system should be established. In addition to traditional theoretical examinations, practical operation assessments and comprehensive ability evaluations should be included in important assessment parts. Industry certifications such as new energy vehicle maintenance technician certification should be introduced to improve students’ vocational competitiveness. In addition, a progressive career guidance of “vocational cognition-job experience-internship” should be carried out, resources should be integrated to expand employment channels, special job fairs should be organized, and a school-enterprise cooperation platform should be built to create more employment opportunities for graduates.

## 5. Conclusion

The German dual-system vocational system provides valuable experience for the development of the local new energy vehicle technology major. Adopting this talent cultivation model helps to improve the quality of talent cultivation, meet the industry's demand for high-quality technical and skilled talents. By optimizing curriculum settings, strengthening practical teaching, and deepening school-enterprise cooperation, students' professional skills and vocational qualities can be effectively improved, and their employment competitiveness can be enhanced. At the same time, it provides practical guidance for the professional construction and teaching reform of higher vocational colleges, helps colleges formulate scientific development strategies, and improves the pertinence and effectiveness of professional construction. It can also provide a reference for the government to formulate industrial and education policies, promoting the healthy development of the new energy vehicle industry and the continuous progress of vocational education.

It is worth noting that, for a long time, Chinese higher vocational colleges have been committed to cultivating high-quality technical and skilled talents. However, their efforts have mainly been self-initiated reforms within the institutions<sup>[10]</sup>. To build a new energy vehicle technology talent cultivation system with Chinese characteristics, it is necessary to break through institutional barriers, establish a market-driven collaborative innovation mechanism, draw on the essence of the dual-system rather than simply copying it, and form a closed-loop ecosystem integrating the education chain, talent chain, and industrial chain, so as to provide high-quality technical and skilled talent support for the development of new industrialization.

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## Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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# Research on the Development Status, Problems, and Countermeasures of China's Cross-Border E-commerce

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**Abstract:** With the global popularization of internet technology and the widespread use of mobile devices, commercial activities are rapidly shifting online, and the global e-commerce market continues to maintain high-speed growth. Cross-Border E-commerce (CBEC), as a new trade model, integrates new technologies and business models, becoming a crucial component of international trade. China, as one of the world's largest e-commerce markets, has seen particularly rapid development in its CBEC sector, which has become an important means of stimulating economic growth and strengthening international cooperation. This paper examines the development history and market status of China's CBEC through literature review and case analysis. It deeply analyzes the prominent issues in tax and legal systems, information infrastructure, credit and payment security, logistics, and talent cultivation. Targeted countermeasures are proposed, including improving tax and legal frameworks, strengthening information infrastructure, perfecting credit and payment security systems, optimizing logistics, and increasing talent development efforts, to promote the healthy and sustainable development of China's CBEC.

**Keywords:** Cross-Border E-commerce; Development Status; Problems; Countermeasures; APA Format

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## 1.Introduction

### 1.1 Background

In recent years, the scale of China's cross-border e-commerce has continued to expand. According to data from the General Administration of Customs of China and the Ministry of Commerce, the import and export scale of China's CBEC reached approximately 1.92 trillion yuan in 2021, an increase of 18.6% year-on-year, accounting for 4.9% of the total import and export volume (State Council Information Office, 2021; State Council Information Office, 2021). Exports alone reached 1.39 trillion yuan, a year-on-year increase of 28.3%. With its flexibility and low-cost advantages, CBEC has challenged traditional trade models while offering new opportunities for the global trade market. The E-commerce Law of the People's Republic of China, which came into effect on January 1, 2019, provides legal protection for the standardized development of China's e-commerce, further promoting the healthy development of the industry.

### 1.2 Research Objectives

CBEC has broken down national trade barriers, establishing an open, multi-layered economic and trade cooperation model that significantly promotes the optimal allocation of global resources. For businesses, it broadens access to international markets; for consumers, it provides a convenient way to acquire high-quality global products. However, alongside its rapid

growth, CBEC faces numerous challenges. This study aims to analyze the current status and major problems of China's CBEC and propose practical development countermeasures.

### 1.3 Research Methods and Content

This paper primarily employs literature review and case analysis. By reviewing relevant domestic and international literature, the theoretical foundation of CBEC is established. Through case studies of Chinese CBEC enterprises, practical problems in the industry's development are revealed.

The paper is divided into five chapters: Chapter 1 is the Introduction; Chapter 2 examines the concept, types, and characteristics of CBEC; Chapter 3 analyzes the development history and market status of China's CBEC; Chapter 4 delves into the existing problems; and Chapter 5 presents the conclusion and policy recommendations.

## 2. Concept, Types, and Characteristics of Cross-Border E-commerce

### 2.1 Concept of Cross-Border E-commerce

E-commerce is a new type of transaction based on modern information technology and internet technology, integrating information flow, capital flow, and logistics. Cross-Border E-commerce (CBEC) specifically refers to international business activities where trading entities from different countries or regions conduct commodity transactions, payment settlements through e-commerce platforms, and ultimately complete the transaction via cross-border logistics services. It includes two main forms: domestic consumers purchasing goods from abroad (direct purchase) and foreign consumers purchasing domestic products (reverse direct purchase).

*Table 2-1 Comparison of Traditional Trade and Cross-Border E-commerce Trade Characteristics*

Feature	Traditional Trade	Cross-Border E-commerce Trade
Trading Parties	Overseas trading companies (B2B, fixed buyers)	Overseas consumers (B2C, unspecified number of consumers)
Transaction Cycle	Periodic	Real-time (irregular)
Sales Characteristics	Large volume, small variety	Small volume, large variety
Transportation Time	Long-term (months)	Short-term (within 2 weeks)
Main Logistics Method	Sea freight	Air freight
Logistics Cost	Low cost (bulk transport)	High cost (individual shipment)
Transaction Method	Offline (paper-based transactions)	Online ordering
Export Clearance	Export declaration obligation (using customs)	No export declaration obligation (submission of export clearance manifest)
Contract Cancellation	Difficult (strict enforcement of trade standards)	Simple (frequent cancellation/return due to consumer change of mind)

### 2.2 Types of Cross-Border E-commerce

Based on the trading entities, CBEC is mainly categorized into the following types:

Business-to-Business (B2B): Transactions between enterprises, which is currently the dominant model in China's CBEC.

Business-to-Consumer (B2C): Enterprises sell products directly to consumers through platforms or independent websites, the most common form.

Consumer-to-Consumer (C2C): Consumers sell goods directly to other consumers through platforms (e.g., Taobao, eBay).

Manufacturer-to-Consumer (M2C): Manufacturers provide products or services directly to consumers, reducing intermediate circulation links and lowering costs.

### 2.3 Characteristics of Cross-Border E-commerce

CBEC, based on the nature of the internet, possesses the following key characteristics:

Globalization: The borderless nature of the internet gives CBEC a global reach, maximizing information sharing, but also introducing risks related to culture, politics, and law.



Multilateralism: CBEC adopts a multilateral model, allowing trade activities with multiple countries simultaneously, unlike the bilateral model of traditional trade.

Intangibility and Paperless: Communication and contract signing between trading parties can be done electronically, significantly improving transaction efficiency.

Concealment: Trading parties can hide their identities and relevant information as needed, which helps protect consumer privacy.

Timeliness: E-commerce is not constrained by time, space, or distance, and can efficiently compress multiple intermediate steps, thus offering high timeliness.

### **3.Current Status of China's Cross-Border E-commerce**

#### **3.1 Development History**

The development of China's CBEC has generally gone through the following stages:

Incubation Stage (1999-2003): Marked by the emergence of Alibaba International (predecessor of 1688.com), primarily providing information display platforms for SMEs and cultivating early CBEC merchants.

2.0 Stage (2004-2012): Transaction activities began to shift online, with payment and logistics gradually digitized. Platforms generated revenue by charging membership fees and transaction fees.

3.0 Development Stage (2013-2018): With the full popularization of the internet and the increase in mobile users, the government began introducing policies to stimulate transactions, such as adjusting tax rates, improving customs clearance efficiency, and establishing Comprehensive Pilot Zones for Cross-Border E-commerce (e.g., Shanghai, Chongqing, Hangzhou) (An, 2017).

Maturity Stage (2019-Present): The refinement of policies and systems has driven continuous industry development. From 2013 to 2021, China's CBEC maintained an average annual growth rate of 24.14% (Korea Ministry of Trade, Industry and Energy, 2021).

#### **3.2 Market Scale and Structure**

##### **3.2.1 Transaction Scale**

The transaction scale of China's CBEC continues to grow rapidly. According to data from the Qianzhan Industry Research Institute and the General Administration of Customs of China, the scale of China's CBEC was 2.7 trillion yuan in 2013, and by 2021, it had reached 19.23 trillion yuan, with an average annual growth rate maintained above 20% (Qianzhan Industry Research Institute, n.d.).

##### **3.2.2 Model Structure**

China's CBEC is still dominated by the B2B model, but the proportion of the B2C model is increasing year by year. In 2019, B2B transactions accounted for 80.5%, while B2C transactions accounted for 19.5% (State Administration of Market Regulation, 2020). This indicates that with the upgrading of consumer demand and the improvement of the logistics system, the cross-border retail model directly facing consumers is developing rapidly.

##### **3.2.3 User Scale**

The scale of cross-border online shopping users continues to expand. At the end of 2017, the number of cross-border online shopping users in China was approximately 66 million, increasing to 265 million by 2021 (State Council Information Office, n.d.). The growth in user scale reflects the increasing demand of Chinese consumers for global products.

#### **3.3 Main Payment Methods**

The main payment methods for China's CBEC are dominated by third-party payment platforms. According to an Adyen survey, Alipay (48%) and Tencent Pay (19%) are the primary payment methods for domestic e-commerce, with international UnionPay and international cards also holding a certain proportion (Adyen, n.d.). The stability and convenience of third-party payments provide an important guarantee for the rapid development of China's e-commerce market.

### **4.Challenges Facing China's Cross-Border E-commerce Development**

Despite its rapid development, China's CBEC still faces numerous challenges in terms of systems, infrastructure, credit,



logistics, and talent.

## **4.1 Tax and Legal System Issues**

### **4.1.1 Tax System Issues**

The online transaction nature of CBEC poses challenges to traditional tax systems:

**Tax Loss Risk:** The hidden nature of cross-border transactions makes it difficult to verify the identity of taxpayers and ensure the authenticity of transactions, leading to tax loss (Yu, n.d.).

**Imperfect Collection and Management System:** The division of labor for tax collection, management, and inspection is unclear, the flow of tax sources is vague, and there are many loopholes in collection and management. Many online operators fail to obtain business licenses or complete tax registration, resulting in inadequate tax payment.

### **4.1.2 Legal System Issues**

**Product Quality Supervision and Rights Protection:** The rate of substandard product quality on CBEC platforms is relatively high. Due to geographical and regulatory restrictions, consumer rights are difficult to protect effectively (Huang, 2019).

**Intellectual Property Protection:** Intellectual property rights, product quality evaluation systems, and legal environments vary across countries in international trade, making the definition of IP rights in CBEC transactions difficult and restricting industry development.

## **4.2 Information Infrastructure Shortcomings**

The realization of e-commerce is highly dependent on information infrastructure. China still has deficiencies in information infrastructure construction:

**Low Informatization Level:** The level of informatization and digitalization in most small and medium-sized enterprises is low, making it difficult to adapt to the digital requirements of international trade.

**Urban-Rural Disparity in Penetration:** Although internet penetration continues to rise, the urban-rural gap remains significant. In 2021, urban internet penetration was 82%, while rural penetration was only 57.5% (State Council Information Office, n.d.). The network environment and penetration rate in rural areas still need to be strengthened.

## **4.3 Credit Deficiency and Payment Security Issues**

**Credit Deficiency:** The problem of counterfeit and shoddy products is serious. Unscrupulous individuals exploit the virtual nature of the internet for fraud, harming consumer interests and affecting the international reputation of CBEC (Wang, n.d.).

**Payment Security:** Cross-border payment systems are highly complex, lacking a comprehensive system and regulation. Differences in exchange rates between countries and the difficulty in accurately assessing the financial status of the counterparty create the possibility of illegal transactions. Furthermore, non-compliant operations by some third-party payment platforms also affect the stability of payment settlements.

## **4.4 Logistics Issues**

Logistics is a critical link in completing CBEC transactions. The main current problems include:

**High Transportation Costs:** The costs of transportation, warehousing, and management for cross-border logistics are significantly higher than domestic costs. Statistics show that the average cost of cross-border logistics is 100 yuan per kilogram, which is 10 times the domestic average (State Administration of Market Regulation, n.d.).

**Long Transportation Time:** Procedures such as customs clearance, inspection, and quarantine are time-consuming, leading to long delivery times. It takes at least 3 days, and up to 3-4 weeks, for goods to reach consumers in China's first and second-tier cities. Consumers generally prefer delivery times within 5 days (Chen, n.d.).

**Insufficient Infrastructure:** The construction of overseas warehouses by Chinese CBEC enterprises is still in its infancy and cannot meet the growing demand. Weak logistics informatization leads to low efficiency and high error rates.

## **4.5 Talent Shortage**

CBEC requires composite talents with expertise in e-commerce, international trade, foreign languages, and marketing. Currently, China faces a severe shortage of CBEC talent, mainly reflected in:

**Shortage of Platform Operation Talent:** A lack of composite talent with practical experience who can skillfully handle store setup, product listing, order processing, and customer service.

Shortage of Marketing Talent: A lack of talent with keen market insight and skilled network marketing techniques (e.g., social media marketing, content marketing).

Shortage of Logistics Talent: A lack of professionals familiar with international logistics processes and capable of handling complex international logistics issues.

Shortage of Data Analysis Talent: A lack of professionals who can use data analysis tools to support corporate decision-making.

## 5. Conclusion and Policy Recommendations

To promote the healthy development of China's CBEC, this paper proposes the following countermeasures:

### 5.1 Improve Tax and Legal Systems

Establish a tax collection and management model adapted to the development of CBEC, clarifying tax subjects, objects, and rates, and simplifying tax procedures. Accelerate the legislative process in the CBEC field, clarify the rights and obligations of all trading parties, and establish sound mechanisms for consumer rights and intellectual property protection to provide legal guarantees for standardized industry development.

### 5.2 Strengthen Information Infrastructure Construction

Increase investment in network infrastructure, especially in central and western regions and rural areas, to improve internet penetration and network speed. Encourage enterprises to upgrade their informatization, promote the establishment of data sharing platforms among government, industry, and enterprises, and utilize big data and cloud computing to enhance operational efficiency.

### 5.3 Perfect Credit System and Payment Security

Establish a unified national CBEC credit evaluation system to enable credit information sharing and joint disciplinary action. Strengthen the supervision of third-party payment platforms, standardize their operations, and ensure payment security. Promote the use of safer payment technologies to prevent financial risks.

### 5.4 Optimize Logistics System

Encourage logistics enterprises to build overseas warehouses and bonded warehouses to shorten delivery times and reduce logistics costs. Support the development of third-party logistics and smart logistics, utilizing technologies like the Internet of Things and artificial intelligence to improve logistics efficiency and transparency. Strengthen coordination among customs, commodity inspection, and other departments to simplify clearance procedures and enhance efficiency.

### 5.5 Increase Talent Cultivation Efforts

Encourage cooperation between universities and enterprises to offer CBEC-related majors and courses, cultivating composite talents. Establish CBEC talent training bases to provide continuous on-the-job training for industry practitioners. Implement talent introduction programs to attract high-end overseas talent, providing intellectual support for the development of China's CBEC.

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# Empowering Cultural and Creative Product Design through AIGC in Tourism Contexts: A Human–AI Co-Creation Perspective

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**Abstract:** Artificial Intelligence Generated Content (AIGC) has become a transformative force reshaping the intersection between digital creativity and cultural tourism. This study investigates how AIGC empowers cultural and creative product design in tourism scenarios and reconstructs the relationship between tourists, culture, and destinations. Building upon human–computer interaction and cultural sustainability theories, a “Human–AI Co-Creation Loop” is proposed to illustrate how cultural narratives can be encoded, visualized, and personalized through AI. Using multi-case analysis from Lijiang (China), Kyoto (Japan), and Barcelona (Spain), this study reveals that AIGC enhances cultural translation, aesthetic diversity, and participatory engagement while posing authenticity and ethical challenges. The research contributes theoretically by integrating AIGC into sustainable tourism design discourse and practically by offering a design-driven framework for cultural innovation in the AIGC era.

**Keywords:** Cultural Tourism; Human-AI Co-Creation; Cultural Sustainability

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## 1.Introduction

Tourism is entering an era of intelligent transformation, where creativity and digital technology intersect to redefine cultural expression and visitor experience. Artificial Intelligence Generated Content (AIGC) represents a new paradigm that enables the automatic generation of images, texts, and artifacts through large-scale machine learning models. Unlike earlier forms of automation, AIGC introduces a generative collaboration between human creativity and computational intelligence, blurring the boundaries between designer, user, and algorithm.

In the context of cultural tourism, AIGC offers both opportunities and challenges. On one hand, it enables the dynamic visualization of cultural symbols and narratives, fostering interactive, personalized, and immersive tourism experiences. On the other hand, it raises critical questions about cultural authenticity, algorithmic ethics, and the preservation of intangible heritage. While museums, creative studios, and tourism boards increasingly adopt AI-based design tools, existing research rarely integrates AIGC into the theoretical discourse of tourism management. Most studies focus on technical or artistic aspects rather than understanding how AIGC reshapes value creation, stakeholder interaction, and destination identity.

Therefore, this study seeks to fill the theoretical and practical gap by proposing a conceptual framework of Human–AI Co-

Creation in Tourism Product Design. Specifically, it addresses three guiding research questions:

- 1.How does AIGC transform the design logic and creative process of tourism cultural products?
- 2.What co-creation mechanisms emerge among AI systems, designers, and tourists?
- 3.How can AIGC contribute to sustainable cultural experience and destination identity?

Theoretically, this research extends the scope of tourism management by integrating design thinking and human–computer interaction into the sustainability discourse. Practically, it provides a design-driven roadmap for applying AIGC to cultural innovation, enabling destinations to balance tradition, creativity, and technological evolution in the post-digital tourism era.

## 2.Literature Review

### 2.1 AIGC and Cultural Creativity

Artificial Intelligence Generated Content (AIGC) represents a generative paradigm in which creative outputs are co-produced by humans and algorithms. It extends beyond automation, emphasizing generative co-creation where AI acts as a partner in creativity rather than a passive tool (Zhao & Yu, 2023). Within the cultural and creative industries, this paradigm reshapes authorship, artistic agency, and aesthetic production (Liu, 2024). Diffusion-based models such as Stable Diffusion and DALL·E have enabled designers to visualize complex ideas rapidly, democratizing creative exploration and accelerating cultural innovation.

Recent research highlights AIGC’s role in heritage preservation and reinterpretation. Guo et al. (2025) applied LoRA-based generative models to Yi ethnic embroidery, demonstrating that AIGC can preserve symbolic authenticity while allowing modern reinterpretation. Similarly, Dai et al. (2024) integrated Stable Diffusion with multi-criteria decision-making methods to regenerate traditional paper-cutting patterns. These studies suggest that AIGC not only generates imagery but also mediates cultural translation, enabling new pathways for heritage revitalization and cultural continuity.

### 2.2 AIGC in Tourism Design

Tourism product design plays a key role in transforming cultural narratives into tangible experiences. AIGC introduces a new design logic by enabling the automated generation and personalization of visual and experiential elements. Kim and Lee (2023) found that AI-generated storytelling enhances perceived authenticity and emotional immersion among visitors. Similarly, Zeng and Li (2022) argued that AI-mediated creative media extend destination narratives beyond physical boundaries, forming distributed tourism experiences across digital and real environments.

Moreover, AIGC promotes participatory engagement in cultural tourism. Wang and Sun (2024) showed that generative design platforms allow tourists to co-create souvenirs and interpret local symbols, marking a shift from passive consumption to active co-creation. This participatory turn aligns with the “experience economy” paradigm (Pine & Gilmore, 1999), where visitors become co-producers of cultural meaning. However, scholars also warn of ethical concerns such as authorship, data use, and the potential erosion of artisanal authenticity (Gretzel & Tussyadiah, 2023).

### 2.3 Theoretical Gap and Research Positioning

Although growing literature explores AI in creative industries, few studies systematically integrate AIGC into the theoretical landscape of tourism management. Three key gaps are identified:

- 1.Theoretical integration between AIGC and sustainable tourism design remains underdeveloped.
- 2.Empirical links between AIGC-driven design and visitor experience outcomes are limited.
- 3.There is a lack of methodological transparency and cross-cultural validation in AIGC-related tourism studies.

This research bridges these gaps by constructing a conceptual framework grounded in design thinking and human–AI collaboration. It situates AIGC not merely as a technology but as a cultural mediator that shapes co-creation, authenticity, and sustainability in tourism product design.

### 2.4 Comparative Summary Table

Research Focus	Representative Studies	Key Findings	Identified Gap
AIGC and Creativity	Zhao & Yu (2023); Liu (2024)	Generative co-creation enhances creative agency	Lack of cultural contextualization

Research Focus	Representative Studies	Key Findings	Identified Gap
AIGC and Heritage	Guo et al. (2025); Dai et al. (2024)	Enables digital regeneration of cultural motifs	Limited tourism application
AIGC in Tourism	Kim & Lee (2023); Zeng & Li (2022); Wang & Sun (2024)	Improves engagement and authenticity	Weak empirical validation
Sustainability & Ethics	Gretzel & Tussyadiah (2023)	Raises authenticity and governance concerns	No framework linking ethics and design

### 3.Theoretical Framework and Methodology

#### 3.1 Conceptual Framework: The Human–AI Co-Creation Loop

This study establishes a conceptual model called the Human–AI Co-Creation Loop, grounded in human–computer interaction and design thinking. The framework conceptualizes AIGC as an interactive ecosystem where humans and AI continuously exchange creative inputs and feedback. The model includes four interconnected stages:

- 1.Cultural Input: Local cultural symbols, stories, and patterns are collected and digitally encoded (e.g., ethnic motifs, traditional crafts, oral histories).
- 2.AI Generation: Diffusion-based and transformer-based algorithms are applied to produce visual or textual outcomes derived from these cultural datasets.
- 3.Human Curation: Designers and cultural practitioners evaluate AI outputs, refining them through interpretive and aesthetic judgment.
- 4.Experiential Output: The co-created results are integrated into tourism cultural products, such as souvenirs, immersive installations, or digital exhibitions, shaping visitor experience and destination identity.

This cyclical interaction emphasizes mutual learning and cultural translation, suggesting that AI amplifies rather than replaces human creativity. The model bridges cultural authenticity with technological adaptability and serves as a design-driven roadmap for sustainable cultural tourism innovation.

#### 3.2 Research Design

A qualitative multiple-case study approach (Yin, 2018) was adopted to capture the complexity of AIGC-enabled creative practices in diverse cultural settings. Three destinations—Lijiang (China), Kyoto (Japan), and Barcelona (Spain)—were selected for their representativeness of heritage, craft, and digital creativity.

Case selection criteria:

- 1.Active integration of AIGC or AI tools in creative production;
- 2.Strong cultural identity and heritage tourism base;
- 3.Evidence of local–global collaboration in creative industries.

Data Collection:

Between 2023 and 2025, data were gathered from multiple sources:

- 21 semi-structured interviews with designers, artisans, and tourism managers;
- Archival materials and project reports (e.g., workshop records, design prototypes);
- Online ethnography of AIGC creative communities and digital exhibitions.

Case Descriptions:

Lijiang: Focused on ethnic pattern workshops using AIGC to reimagine Yi embroidery; included 7 designers and 5 cultural practitioners.

Kyoto: Examined three heritage studios experimenting with AI-assisted textile visualization.

Barcelona: Investigated two creative startups co-developing AI-generated souvenirs with tourism boards.

All interviews were transcribed and analyzed with NVivo 14, following a three-step thematic coding (open, axial, selective).

Two independent researchers cross-checked the coding for consistency, ensuring intercoder reliability.

To ensure credibility and transferability, triangulation was performed across cases and data types. The multi-case comparison



enables the identification of both shared mechanisms and local adaptations of AIGC-driven design.

### 3.3 Data Analysis and Coding

Data analysis was conducted inductively through a constant comparative method. The goal was to align emergent themes with the Human–AI Co-Creation Loop.

Step 1: Open coding – identification of recurrent patterns from raw transcripts.

Step 2: Axial coding – grouping related concepts into higher-level categories.

Step 3: Selective coding – integrating categories into theoretical dimensions.

*Sample Coding Table*

Raw Excerpt (Participant Quote)	First-Level Code	Second-Level Theme
“AI gave me unexpected ideas—it felt like working with another designer.” (Lijiang designer)	Co-creation experience	Human–AI collaboration
“The generated pattern kept the spirit of Yi culture but modernized it.” (Lijiang artisan)	Cultural reinterpretation	Authenticity mediation
“Tourists loved that they could tweak designs instantly on their phones.” (Barcelona manager)	User participation	Experience personalization

This coding process ensured transparency and traceability between data and theoretical abstraction. Emerging themes—“collaboration,” “reinterpretation,” and “personalization”—formed the analytical foundation for cross-case comparison.

### 3.4 Cross-Case Comparative Insights

Comparative analysis revealed three co-creation patterns:

a. Cultural Translation (Lijiang): AIGC was used to reinterpret ethnic symbols while maintaining cultural integrity.

b. Collaborative Craftsmanship (Kyoto): AI-assisted artisans accelerated design iteration while preserving traditional aesthetics.

c. Participatory Personalization (Barcelona): Tourists engaged with AI-generated souvenirs, shaping experiential authenticity.

Despite contextual variations, all cases demonstrated AIGC’s mediating role between authenticity and innovation, suggesting a universal mechanism of cultural-technical hybridity in creative tourism.

## 4. Results and Discussion

### 4.1 Overview of Findings

The analysis revealed that AIGC’s application in tourism product design generates three interrelated co-creation mechanisms—cultural translation, collaborative craftsmanship, and participatory personalization—that correspond to distinct modes of human–AI interaction. These mechanisms collectively illustrate how AIGC mediates between cultural authenticity and technological innovation, creating new forms of sustainable cultural experience.

### 4.2 Cultural Translation in Lijiang

In Lijiang, AIGC became a tool for cultural reinterpretation. Local designers employed diffusion models to regenerate Yi embroidery motifs using prompts derived from traditional stories. Interviews indicated that AIGC allowed “translation” of intangible heritage into contemporary aesthetics while preserving symbolic meaning.

“AI gave me a new way to visualize our patterns—it doesn’t replace my craft, but it helps me imagine modern forms that still feel Yi.” — (Lijiang Artisan, Interview #6)

Participants emphasized co-agency between human intuition and algorithmic exploration. The process reflects a hybrid form of authorship where AI acts as a cultural interpreter rather than a mere generator. This aligns with recent scholarship suggesting that AIGC mediates between cultural continuity and creative disruption (Guo et al., 2025).

### 4.3 Collaborative Craftsmanship in Kyoto

In Kyoto, heritage studios adopted AIGC-assisted visualization to reinterpret textile patterns. The process did not aim to automate craftsmanship but to enhance iteration and ideation.

“The AI’s suggestions speed up our prototype cycle, but the final judgment is always human.” — (Kyoto Studio Director,

## Interview #3)

Field notes show that artisans viewed AIGC as a “co-designer” that accelerated experimentation while maintaining the aesthetic integrity of Kyoto’s heritage crafts. The symbiosis between algorithmic efficiency and manual refinement represents a collaborative authorship model, consistent with Boden’s (2022) notion of “computational creativity.”

#### 4.4 Participatory Personalization in Barcelona

The Barcelona case illustrated a different form of co-creation where tourists directly interacted with AIGC systems to design personalized souvenirs. Through AI-driven design kiosks, visitors could modify patterns or generate visuals based on local icons (e.g., Gaudí architecture).

“Tourists enjoyed creating their own designs—it made them feel part of Barcelona’s creative spirit.” — (Startup Manager, Interview #2)

Observation data indicated that such participation enhanced emotional engagement and perceived authenticity. Tourists perceived AI as a playful medium connecting technology, art, and local culture. This finding supports Pine and Gilmore’s (1999) experience economy theory, where value emerges through active participation and personalization.

#### 4.5 Cross-Case Discussion: Authenticity, Creativity, and Ethics

Across cases, AIGC functions as both a creative partner and a cultural mediator. However, its integration raises new tensions between authenticity, creativity, and ethics.

**Authenticity:** While AIGC facilitates reinterpretation, excessive algorithmic manipulation risks cultural dilution. Hence, human curation remains crucial for maintaining symbolic depth.

**Creativity:** The co-creation process demonstrates that AI expands human ideation capacity rather than replacing it, fostering pluralistic aesthetics and innovation.

**Ethics:** Participants expressed concerns over authorship and cultural data ownership. Some feared algorithmic bias might “flatten” nuanced heritage forms, echoing Gretzel & Tussyadiah’s (2023) warnings about digital ethics in tourism.

Overall, AIGC’s success in tourism product design depends on achieving a balance between automation and authorship, where human interpretation anchors algorithmic creativity within local cultural contexts.

### 5. Design Framework Proposal

#### 5.1 Framework Overview

Building upon the empirical findings, this study proposes an expanded Human–AI Co-Creation Design Framework that illustrates how AIGC can systematically empower cultural and creative product design within tourism contexts. The framework synthesizes insights from the three case types—cultural translation, collaborative craftsmanship, and participatory personalization—into a unified model linking inputs, processes, and outcomes.

The framework integrates three key theoretical dimensions:

**Cultural Continuity:** Ensuring symbolic authenticity through heritage-informed datasets and local stakeholder involvement.

**Technological Mediation:** Leveraging AIGC for creative iteration, pattern generation, and user customization.

**Experiential Value Creation:** Translating AI-enhanced cultural products into immersive, participatory visitor experiences that reinforce destination identity.

Conceptually, the model illustrates a dynamic feedback system where AI outputs are continually refined through human judgment, resulting in adaptive cultural products that evolve with both user preferences and heritage integrity.

#### 5.2 Structure of the Human–AI Co-Creation Framework

The proposed framework (Figure 1, textually described below) contains three layers:

Layer 1: Input (Cultural Knowledge Layer)

Includes cultural datasets, heritage archives, and narrative symbols that serve as the raw material for AIGC training or prompting.

Layer 2: Process (Generative Interaction Layer)

Encompasses human–AI collaboration, iterative co-design, and value negotiation between cultural meaning and algorithmic possibility.

### Layer 3: Output (Experiential Layer)

Produces tangible tourism products and intangible cultural experiences, evaluated through visitor perception, emotional engagement, and authenticity satisfaction.

Feedback loops connect these layers: tourists' reactions inform new datasets; designers' curatorial decisions influence AI's aesthetic directions; and cultural communities assess alignment with heritage values. This loop operationalizes the "co-evolution" of human creativity and algorithmic intelligence in tourism design.

### 5.3 Theoretical Contribution

This framework advances the field of tourism management in three theoretical aspects:

- Extending the Experience Economy:** By embedding AIGC within design processes, the model updates Pine and Gilmore's (1999) framework to reflect the rise of algorithmic participation in co-created experiences.
- Bridging Design Thinking and Sustainability:** It connects aesthetic innovation with cultural sustainability, highlighting how AI-driven design can reinforce local identity rather than homogenize it.
- Redefining Authenticity:** The study proposes "algorithmic authenticity," referring to human-curated AI outputs that preserve symbolic depth while achieving creative renewal.

### 5.4 Practical Implications

For tourism managers, the framework provides strategic implications in three areas:

**Design Management:** Encourage multidisciplinary collaboration among technologists, designers, and heritage experts to align AI capabilities with cultural goals.

**Destination Branding:** Integrate AIGC-driven co-creation into branding narratives to attract creative-class tourists seeking participatory experiences.

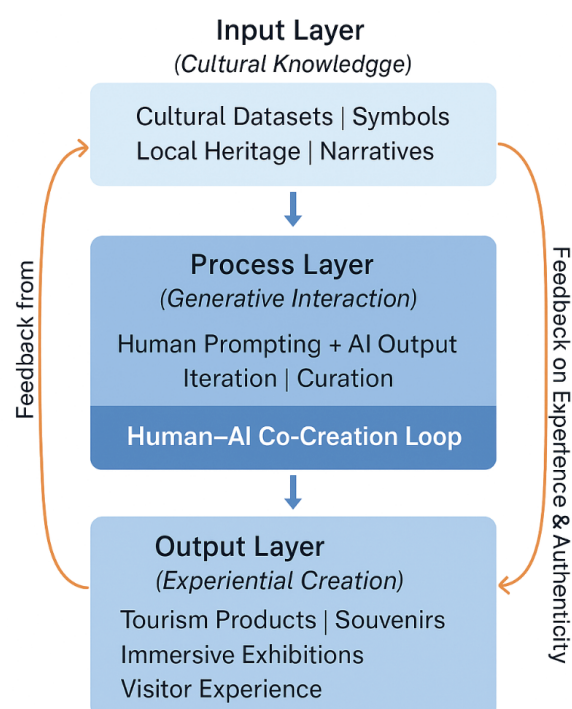
**Cultural Governance:** Develop ethical guidelines for algorithmic use, ensuring cultural data ownership and community participation in creative decision-making.

### 5.5 Limitations and Future Directions

This framework remains conceptual and requires further empirical validation. Future research could:

- Conduct quantitative studies on visitor perception of AIGC-enhanced experiences;
- Apply experimental designs to measure the impact of AI-generated aesthetics on satisfaction and cultural connection;
- Explore longitudinal effects of human–AI collaboration on cultural sustainability within tourism destinations.

Figure 1. Human-AI Co-Creation Design Framework



The framework visualizes a three-layer model linking cultural inputs, human–AI generative processes, and experiential outputs. Feedback loops connect tourists, designers, and AI systems, illustrating the co-evolution of creativity, authenticity, and cultural sustainability.

## 6. Managerial Implications and Theoretical Reflection

### 6.1 Managerial Implications

The findings of this study provide actionable insights for tourism managers, policymakers, and creative industry stakeholders seeking to harness AIGC for sustainable cultural innovation.

#### a. Integrating AI into Design Governance:

Tourism organizations should establish design governance frameworks that balance innovation with cultural authenticity. This involves forming interdisciplinary committees—including designers, technologists, cultural experts, and ethicists—to oversee AIGC deployment and ensure cultural sensitivity in data use and output evaluation.

#### b. Developing AI-Enhanced Experience Systems:

Destinations can adopt AIGC as part of their experience design ecosystem. For example, AI-enabled kiosks and digital exhibition platforms allow visitors to participate in real-time content generation, reinforcing co-creation and emotional attachment to the destination.

#### c. Empowering Local Communities:

The study underscores that AIGC should not replace local creators but empower them. Training programs that teach heritage artisans how to use AIGC tools can democratize innovation and sustain intangible cultural heritage within evolving tourism markets.

#### 4. Ethical and Regulatory Frameworks:

Policymakers must address emerging ethical dilemmas—such as cultural data ownership, algorithmic bias, and authorship rights—through adaptive regulatory measures and transparent disclosure practices.

### 6.2 Theoretical Reflection

The study's theoretical reflection revolves around three critical dimensions—authenticity, co-creation, and technological agency—each reshaped by the rise of AIGC.

#### a. Revisiting Authenticity:

Traditional tourism research distinguishes objective and existential authenticity (Wang, 1999). AIGC introduces a third dimension—algorithmic authenticity—where cultural meaning is mediated through AI outputs but curated by human judgment. This expands the authenticity discourse from “being true to tradition” to “being true to cultural intention.”

#### b. Reframing Co-Creation:

Building on Prahalad and Ramaswamy's (2004) framework, AIGC redefines co-creation as triadic collaboration among humans, AI systems, and cultural environments. This transformation implies a new paradigm of tourism value creation based on interactive learning and dynamic adaptation.

#### c. Reconceptualizing Technological Agency:

The study challenges anthropocentric assumptions by recognizing AI as an active creative partner. Yet, this partnership must remain under ethical human oversight to preserve meaning, responsibility, and cultural accountability.

### 6.3 Theoretical Integration with Tourism Management

By integrating design thinking, human–computer interaction, and sustainability perspectives, this study contributes to bridging tourism management and creative design theory. AIGC operates not merely as a technological innovation but as a methodological transformation in managing cultural experiences, destination identities, and stakeholder relations.

### 6.4 Summary

This chapter positions AIGC as both a managerial tool and a theoretical lens for reimagining tourism innovation. The reflections underscore that the future of tourism management depends on cultivating responsible creativity—one that harmonizes artificial intelligence, human imagination, and cultural heritage.

## 7. Conclusion and References

### 7.1 Conclusion

This study explored how Artificial Intelligence Generated Content (AIGC) empowers cultural and creative product design within tourism contexts, addressing the interplay between technological innovation and cultural authenticity. Through a qualitative multi-case study of Lijiang (China), Kyoto (Japan), and Barcelona (Spain), the research developed and validated the Human–AI Co-Creation Design Framework, revealing three core mechanisms—cultural translation, collaborative craftsmanship, and participatory personalization.

The findings highlight that AIGC serves not as a replacement for human creativity but as a catalyst for cultural renewal, facilitating co-evolution between tradition and modernity. Human–AI collaboration enhances design efficiency, expands creative imagination, and deepens visitor engagement through participatory and personalized experiences.

Theoretically, this research introduces the notion of algorithmic authenticity, extending existing tourism authenticity theories (Wang, 1999) to account for AI-mediated creative production. Practically, it provides a governance-oriented framework for tourism destinations to balance innovation with cultural integrity.

Ultimately, the study concludes that sustainable tourism innovation in the AIGC era requires a triadic equilibrium among human creativity, technological agency, and cultural sustainability—a balance that ensures intelligent design serves not only economic value but also cultural meaning and ethical responsibility.

### 7.2 Contributions

**Theoretical Contribution:** Expands tourism management discourse by integrating AIGC into theories of co-creation, authenticity, and sustainable design.

**Methodological Contribution:** Provides a replicable qualitative model that bridges design research with tourism management inquiry.

**Practical Contribution:** Offers actionable strategies for integrating AIGC into destination branding, creative industry development, and cultural governance.

### 7.3 Future Research Directions

Future research can advance this study by:

- a. Quantitatively measuring tourists' perception of AIGC-mediated authenticity.
- b. Exploring cross-cultural differences in AI adoption across various tourism contexts.
- c. Applying longitudinal approaches to assess the sustainability of Human–AI co-creation practices.

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# Research on the Upgrading Path of Foshan Ceramic Industry Based on Data Elements

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**Abstract:** As data becomes a key force reshaping industrial organization and resource allocation mechanisms, traditional manufacturing faces an urgent need to upgrade its governance structures in the digital economy era. Drawing on the typical practices of the Foshan ceramics industry, this paper constructs a three-mechanism model of “data standardization—platform-based collaboration—data public goods supply,” systematically revealing how data drives traditional industrial upgrading. The Foshan practice demonstrates that data has become a core driving force for the high-quality development of traditional manufacturing. The study further proposes an upgrading path driven by standardization, supply chain collaboration, public goods orientation, and ecosystem-based sustainable development, providing a reference for the digital and data-driven transformation of traditional industries.

**Keywords:** Data Elements; Ceramics Industry; Industrial Upgrading; Path Research

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## 1.Introduction

### 1.1 Research Background and Problem Statement

As the global digital economy enters a phase of rapid development, data has transformed from a traditional information resource into a new type of production factor capable of directly creating value and shaping competitive advantage. Compared with traditional production factors such as labor, capital, and land, data exhibits non-consumable, replicable, combinable, and highly spillover-oriented characteristics, enabling it to reshape industrial organization and resource allocation mechanisms on a larger scale and at a deeper level. Since the state first explicitly identified “data as a new type of production factor,” market-oriented reforms of data factor allocation have continued to deepen, and data’s strategic position in promoting the digital, intelligent, and green transformation of traditional industries has been continuously rising.

The ceramics industry is one of the traditional manufacturing sectors in my country with the most complete industrial chain, the largest scale, and the most significant regional agglomeration. Foshan, as the core base of the national ceramics industry, possesses a complete industrial chain system encompassing raw material supply, production and manufacturing, equipment manufacturing, logistics and transportation, and marketing channels. However, the long industrial chain, numerous participants, complex supply chain structure, and fragmented transaction links have led to long-standing structural problems in the industry, such as information opacity, insufficient transaction credibility, low collaborative efficiency, weak technological innovation capabilities, and financing difficulties for small and medium-sized enterprises. The root cause of these problems lies in the lack of unified data standards and interfaces within the industry. Severe data silos exist between

enterprises, making it difficult to collect, verify, and share real production and operational data, resulting in inefficient resource allocation and limited industrial chain governance capabilities.

Faced with the aforementioned pain points, data has become a crucial tool for the ceramics industry to overcome bottlenecks. In recent years, with the implementation of the national “Data Elements ×” Three-Year Action Plan (2024-2026), Foshan has actively responded to policy requirements by building a data element market environment, promoting data platform construction, developing data public goods, and exploring the circulation of data assets, giving rise to a number of innovative “Data Elements × Ceramic Industry” application cases. In particular, Foshan Zhongtaolian Supply Chain Service Co., Ltd. ( hereinafter referred to as “Zhongtaolian Supply Chain Company” ) has significantly improved resource allocation efficiency and governance capabilities in the ceramics industry by building an industry-wide data standard system, developing data public goods such as tax payment assistance and inclusive finance, and promoting the circulation and application of data in multiple scenarios across the industrial chain through a “scenario + standard + technology + data” model.

However, despite the pioneering breakthroughs achieved by Foshan’s ceramics industry in the application of data elements, existing academic research focuses more on the macro-level development of the digital economy or the application of specific technologies, lacking a systematic analysis of the specific mechanisms, governance logic, and upgrading paths of data elements in the traditional manufacturing industry chain. Especially in traditional industries like ceramics, with their complex structures and diverse chains, in-depth theoretical explanations are still lacking regarding how data functions within the industrial chain, how it reshapes industrial organization, and how it evolves into a public good that enhances governance effectiveness.”

Therefore, it is necessary to construct an explanatory theoretical framework based on summarizing the Foshan practice, to answer the question of how data elements drive the ceramic industry to upgrade from “experience-driven” to “data-driven”, thereby providing a scientific basis for the digital transformation of traditional manufacturing industry.

## **1.2 Research Objectives and Significance**

The overall goal of this study is to systematically analyze, based on the typical practices of the Foshan ceramics industry, how data elements can reshape the governance structure of the traditional industrial chain through standardization, platformization, and public goods mechanisms, thereby promoting the high-quality development of the ceramics industry. Specifically, this study aims to achieve three aspects:

### **1.2.1 Constructing the Mechanism of Data-Driven Transformation in Traditional Industries from a Theoretical Perspective**

Existing research lacks a mechanistic analysis of the application of data elements in traditional manufacturing. Based on the characteristics of the ceramic industry chain and the attributes of data elements, this study proposes a three-mechanism model of “data standardization—collaborative platformization—public goods supply,” which systematically explains the value formation logic of data elements within the industry chain from a micro-governance perspective, and helps to enrich the existing theoretical system of data elements.

### **1.2.2 Summarizing the experience of data elements in Foshan’s ceramic industry from a practical perspective**

The digital transformation practices of Foshan’s ceramics industry are typical and representative. This study integrates key cases from Foshan, including data platform construction, data public goods development, and data asset circulation, to extract replicable and scalable industrial digitalization solutions, providing practical guidance for the transformation of traditional industries in other regions.

### **1.2.3 Propose feasible industrial upgrading paths from a policy perspective**

By summarizing the governance value of data elements for traditional industries, this study proposes an upgrade path that prioritizes standardization, empowers through platforms, emphasizes public goods, and promotes ecological development, providing policy support for governments to build a data element market and promote the development of digital manufacturing.

Overall, this study not only makes theoretical contributions (mechanism innovation), practical contributions (summarizing cases), and policy contributions (proposing pathways), but also provides important insights into how China’s traditional

manufacturing industry can maintain its competitive advantage in the digital economy era.

### 1.3 Research Questions and Main Contents

Based on the research background and objectives, this study focuses on the following three core questions:

- (1) How do data elements play a role within the traditional ceramic industry chain? That is, how can data reduce transaction costs and enhance the industry's credit foundation through mechanisms such as standardization, credibility, and traceability?
- (2) How can digital platforms become a new type of infrastructure for collaborative governance of the ceramic industry chain? That is, how can platforms improve the overall collaborative capabilities and resource allocation efficiency of the industry chain through data sharing, real-time interaction and intelligent scheduling?
- (3) How can data public goods evolve into public goods in the ceramics industry and enhance industry governance capabilities? That is, how can data be transformed into public governance tools in scenarios such as tax payment, finance, and certification to improve regulatory efficiency and industry transparency?

## 2. Literature Review

### 2.1 Research Progress on Data Elements

With the rapid development of the digital economy, data, as a new type of production factor, has become an important topic in academia and policy circles. The "Data Factor White Paper (2022)" released by the China Academy of Information and Communications Technology (CAICT) systematically proposed for the first time that "data factors" should be regarded as a resource form that can directly participate in production activities and create economic benefits, emphasizing its resource-based, asset-based, and scenario-dependent characteristics. With the gradual refinement of this definition, the academic community has conducted extensive discussions on the value formation logic, operational mechanisms, and institutional arrangements of data elements.

From a macro perspective, the rise of data elements has driven the reshaping of resource allocation logic. Zhang Yihui and Liu Cheng systematically deconstructed the resource allocation theory of the digital economy era from four dimensions: data, information, organizational form and market competition. They pointed out that digitalization has brought about a triple effect of "technology-driven, platform competition and institutional change", which has caused profound changes in the traditional resource allocation rules in three scenarios: labor, industry and government governance<sup>[1]</sup>. This analysis reveals that data elements are not only technical tools but also carry institutional implications for reshaping economic governance systems.

In addition, Chen Menggen et al. sorted out the development path of China's data element market and pointed out that although the current data element market has made significant progress in the construction of trading platforms and institutional supply, it still faces problems such as imperfect trading rules, insufficient infrastructure and unsound regulatory system. It is necessary to work together from three aspects: institutional foundation, market operation and technical support to further advance the market-oriented allocation reform of data elements<sup>[2]</sup>. Ouyang Rihui and Xu Yuanbin started from the reform path of the "15th Five-Year Plan" and emphasized that the reform of data elements should follow the principle of "establishing before breaking down" and build a data management system, data basic system, data circulation and trading model and asset management system to form a sustainable reform promotion mechanism<sup>[3]</sup>.

Overall, existing research has extensively explored the connotation, market-based allocation, institutional guarantees, and development paths of data elements, but it still lacks detailed analysis on how data elements are implemented within specific industrial chains and how they are transformed into production and governance capabilities.

### 2.2 Research on Data Elements and Industrial Development

At the micro-enterprise level, a series of studies have demonstrated that data elements have significant performance improvement and efficiency enhancement effects. Zhang Xiaofei et al. found through multi-period difference test of A-share listed companies that the market-oriented allocation of data elements can significantly promote the specialization of enterprises. Its mechanism of action includes reducing external transaction costs, alleviating financing constraints and expanding market size<sup>[4]</sup>. This effect of data elements is more significant for small and medium-sized enterprises, non-state-owned enterprises and enterprises with high degree of supply chain information asymmetry, indicating that data elements have a governance effect of "reducing uncertainty and improving the operating environment of weak entities".

At the industry level, the relationship between data elements and high-quality industrial development has been systematically demonstrated. Wang Xiaowen et al. used listed manufacturing companies as samples and found that digital industry agglomeration accelerates the formation of new quality productivity in manufacturing through mechanisms such as technology integration, supply chain collaboration and industrial chain efficiency optimization <sup>[5]</sup>. This study reveals that data elements play an important role in improving the overall efficiency and innovation momentum of the industry.

Another line of research emphasizes the mechanism by which data assets release value through industrial-chain linkages. Zhang Benxiu et al. pointed out from the perspective of industrial chain information linkage that enterprises can improve total factor productivity by expanding the scale of data assets, and this productivity improvement depends on environmental conditions such as the degree of digitalization of upstream and downstream industries, market competition level and customer concentration <sup>[6]</sup>. This study shows that data assets function as a form of “networked asset,” whose value depends on the level of industrial-chain collaboration.

From the perspective of supply chain resilience, Li Yili et al. constructed a theoretical framework of “data elements - supply chain resilience - new quality productivity” and found that data elements can further promote the digital transformation of enterprises and improve new quality productivity by enhancing the agility, responsiveness and resilience of the supply chain <sup>[7]</sup>. This study provides an important reference for understanding how data elements play a governance role in complex industrial chains.

In addition, Zeng Hao et al. pointed out from the perspective of data element governance that data element governance can significantly improve the new quality productivity of enterprises through optimizing talent allocation, improving the efficiency of capital financing and promoting digital transformation, and further bring about the spillover effect of total factor productivity and enterprise value growth <sup>[8]</sup>.

Based on the above research, the academic community generally believes that the role of data elements in industrial development is mainly reflected in reducing transaction costs, enhancing supply chain resilience, promoting specialization, improving innovation capabilities, and improving governance structures. However, most existing studies use macro-level or cross-industry samples, lacking in-depth scenario-based research on specific sub-sectors of traditional manufacturing, and even more so, lacking a mechanistic analysis of how data elements form value within a single industrial chain.

### 2.3 Definition of Data Elements

In order to ensure the theoretical consistency of the research and the rigor of the model construction, it is necessary to clearly define the “data elements”. According to the authoritative definition of the Data Elements White Paper (2022) of the China Academy of Information and Communications Technology, data elements refer to data resources that are recorded electronically in the production and operation process and can create economic benefits for users or owners, including datasets, data public goods, and information generated based on data, which are collected, organized, and processed according to specific production needs <sup>[9]</sup>.

Three core characteristics can be extracted from this definition:

- (1) Data elements are highly processable and structured. Only data that has been collected, cleaned, processed, and structured can enter production activities and have economic value.
- (2) Data elements have asset value and are tradable. Data elements not only have internal use value, but can also form data public goods, data reports and data services, and realize asset value through market transactions.
- (3) Data elements are subject to both scenario-dependent and institutional-dependent characteristics. Data itself does not generate value; its value is realized through specific scenarios such as tax payment verification, supply chain collaboration, production scheduling, and financial services, and depends on data standards, data governance, and circulation mechanisms.

Based on this, this paper understands data elements as “complex resources that can reduce information asymmetry, improve governance capabilities, enhance collaborative efficiency, and be transformed into public goods through platform mechanisms.” This definition will serve as the foundation for subsequent theoretical model construction and case analysis.

### 2.4 Literature Review and Research Gaps

Existing literature has extensively discussed the connotation, institutional role, industrial function, and governance

mechanisms of data elements, reaching the following consensus:

First, data elements have become an important force in the reshaping of resource allocation and industrial organization. Their mechanism of action involves reducing transaction costs, improving information transparency, strengthening supply chain resilience, and improving industrial chain collaboration<sup>[1, 4-7]</sup>.

Second, the value of data elements depends significantly on the industrial structure and institutional environment. Their assetization, productization and marketization processes all require the support of supporting data standards, governance mechanisms and circulation systems<sup>[2,3]</sup>.

Third, data elements have a stronger empowering effect on SMEs and long-chain industries with multiple participants, especially in reducing uncertainty and improving the foundation of trust<sup>[4,7]</sup>.

However, from the perspective of this study, existing research still has three obvious shortcomings:

First, there is a lack of in-depth research on the segmented industrial chains of traditional manufacturing. Existing literature mostly focuses on high-tech industries or manufacturing as a whole, and there is insufficient discussion on the specific role and mechanism of data elements in traditional industrial chains such as ceramics, which are complex in structure, have long chains, and involve many entities.

Second, there is a lack of a “mechanistic” theoretical framework. Although existing research has explored the role of data elements, there is still a lack of theoretical models that can systematically explain “how data elements drive industrial chain upgrading,” especially a framework that combines data elements with elements such as industrial chain collaboration, transaction credibility, and public governance.

Third, there is a lack of contextualized and case-based research. Most data element studies emphasize statistical significance, while paying less attention to institutional innovation and governance practices in specific cities and industrial clusters. For example, the application of data elements in the Foshan ceramics industry has not been systematically studied in academia.

Based on the aforementioned literature gaps, this paper will take the Foshan ceramics industry as the research object, construct a three-mechanism theoretical model of “data standardization- platform-based collaboration-public goods supply”, systematically analyze the role path of data elements in the traditional industrial chain, and verify the theoretical model through typical practical cases, so as to provide new theoretical explanations and policy implications for the digital upgrading of traditional manufacturing industry.

### **3.A Three-Mechanism Model for Data-Driven Upgrading of Traditional Industries**

Data has become a core force driving the digital transformation of traditional manufacturing and the restructuring of the industrial chain governance system. However, in specific industry contexts, the value of data is not naturally presented, but rather gradually manifested, structured, and tradable through multiple mechanisms such as institutionalization, platformization, and productization, thereby forming a sustainable driving force within the industrial chain. The traditional ceramic industry chain is long, involves many entities, has fragmented links, and has a complex governance structure. It is a typical industry characterized by “weak digital foundation, weak collaborative capabilities, and a weak credit system,” thus better reflecting the deep-seated governance value of data. Based on the research questions raised above, this chapter constructs a three-mechanism model of “data standardization, platform-based collaboration, and public goods provision” to systematically explain how data plays a role within the ceramic industry chain, how platform infrastructure enhances collaborative capabilities, and how data public goods provide governance and public goods value, laying a theoretical foundation for the subsequent analysis of the Foshan ceramic industry case.

#### **3.1 Mechanism 1: Data Standardization to Build a Trustworthy Transaction System**

Data standardization is the starting point for data elements to enter the industrial chain. The traditional ceramics industrial chain has long suffered from problems such as information silos, discrepancies between accounts and actual products, and disconnected processes. The core challenge lies in the lack of verifiable, comparable, and traceable data formats and interfaces, leading to high transaction costs, a lack of trust, and difficulties in supervision. The ceramics industry suffers from inconsistencies in multi-source data in raw material transactions, logistics, contract performance, and fund settlement. Enterprises often cannot form a stable understanding of each other’s production and transaction information, making it



difficult to establish a foundation of trust and a verifiable transaction chain.

In this context, data standardization mechanisms, through unified coding systems, data structures, interface specifications, and collection rules, enable the organization, alignment, and verification of previously scattered, heterogeneous, and unconnected data. The primary benefit of data standardization lies in improved verifiability. For example, by structuring data such as raw material delivery orders, logistics tracks, warehousing records, payment records, and invoice information, and establishing unified field formats and verification rules, automatic data comparison across enterprises and processes can be achieved, thereby reducing information asymmetry and verification costs during transactions.

Secondly, data standardization enhances authenticity and credibility. When logistics, information flow, capital flow, and invoice flow can be cross-verified under a unified data standard, businesses and regulatory authorities can identify abnormal transactions, fraudulent shipments, and falsified invoices in real time. This “four-flow integration” verification mechanism essentially establishes an industry-level, authentic business chain through data standardization, ensuring that any anomalies in any link are exposed within the chain.

Secondly, data standardization provides a stable data foundation for subsequent collaborative platforms. Platform-based collaboration relies on high-quality data, and the foundation of high-quality data is unified standards. Without standardization, platforms cannot implement algorithm scheduling, regulators cannot achieve penetrating supervision, and financial institutions cannot conduct data-driven risk control assessments. Therefore, data standardization not only improves transaction efficiency but also reshapes the credit foundation of the entire industry, making it the most fundamental and crucial link in the entire three-mechanism model.

In summary, the data standardization mechanism directly addresses one of the research questions: How do data elements play a role within the traditional ceramic industry chain?

Its core contribution lies in:

- (1) Improve the comparability, verifiability and traceability of data;
- (2) Establish an industry-level credit system to reduce uncertainty;
- (3) Reduce transaction friction and verification costs;

Provide the underlying data foundation for subsequent collaboration and data public goods.

### **3.2 Mechanism Two: Platform-based Collaboration to Reconstruct the Governance Structure of the Industrial Chain**

Once data standardization is achieved, the second layer of value created by data elements is reflected in platform-based collaboration. Collaboration in the traditional ceramics industry mainly relies on methods such as manual telephone communication, WeChat group communication, and experience-based judgment, leading to lagging production scheduling, disconnected logistics plans, large inventory fluctuations, and low efficiency in supply and demand matching. Because the chain is long and enterprises are highly dispersed, the absence of a real-time and transparent information-sharing mechanism keeps the entire industrial chain in a state of “local optimization but overall inefficiency.”

The introduction of digital platforms has transformed this governance structure. Through the real-time collection, cleaning, and integration of standardized data, digital platforms enable information from all stages to be uploaded to the blockchain, shared, and visualized in real time. For example, on the platform, data such as production plans, inventory status, logistics conditions, and raw material requirements of various enterprises can be integrated in real time, thereby achieving real-time supply and demand matching, intelligent scheduling, and predictive decision-making. The core logic of platform-based collaboration includes the following three aspects.

First, information transparency leads to improved collaborative efficiency. When the supply, production, logistics, and sales ends can share real-time information on a unified platform, demand forecasting becomes more accurate, production planning more forward-looking, inventory management more refined, and resource waste significantly reduced. Enterprises no longer rely on manual communication but instead leverage the platform’s data visualization tools to achieve a “visible supply chain.” Second, algorithmic governance is reshaping the supply chain scheduling mechanism. Based on structured data and predictive algorithms, the platform can automatically generate logistics routes, production scheduling plans, and raw material



replenishment plans, thereby reducing erroneous decisions caused by human experience. For industries like ceramics, which are highly volatile and experience rapid demand changes, algorithmic scheduling enhances the resilience of the supply chain, enabling the industry to respond to market changes more quickly.

Third, the construction of collaborative networks enhances the resilience of the industrial chain. The platform connects suppliers, manufacturers, logistics providers, distributors, and financial institutions, transforming the industrial chain from a “linear structure” to a “network structure.” The network structure offers higher redundancy and more pathways between nodes, helping to reduce the risk of single points of failure and improve the overall stability of the industrial chain.

The platform-based collaboration mechanism addresses the second research question: How can digital platforms become a new type of infrastructure for collaborative governance of the ceramic industry chain?

Through data sharing, real-time interaction, algorithm scheduling, and cross-entity collaboration, platform-based governance has achieved:

- (1) Reduce chain uncertainty;
- (2) Improve the efficiency of production and logistics coordination;
- (3) Improve the accuracy of supply and demand matching;
- (4) Enhance the resilience of the industrial chain;
- (5) Achieve systematic governance across enterprises and across processes.

### 3.3 Mechanism Three: The Public Goods Supply Mechanism of Data- Driven Public Goods

The value of data elements in the industrial chain is ultimately reflected in “productization,” that is, developing tradable, verifiable, and replicable data public goods based on high-quality data, thus forming public goods for industrial governance. The traditional ceramics industry faces typical industrial public problems such as difficulty in paying taxes, weak credit, difficulty in financial risk control, and high costs of quality certification. These public problems are characterized by strong externalities and the lack of incentive for private enterprises to bear them alone. Therefore, it is necessary to achieve the supply of industry-level public goods through data public goods.

A data public goods further processes standardized platform data into products with governance effectiveness, such as “chain of evidence certificates,” “data credit reports,” “risk control models,” and “quality credibility certificates.” These products have the following four characteristics.

First, replicability. Data public goods can be quickly replicated and used in multiple enterprises and scenarios with low marginal costs, which is conducive to improving the overall governance efficiency of the industry.

Second, there are public governance effects. For example, chain-of-evidence certificates can help regulators identify genuine transactions, data credit reports can improve corporate financing capabilities, and risk control models can reduce risks for financial institutions. This means that data public goods possess the attributes of public goods, which can enhance the transparency and standardization of the entire industry.

Third, it has strong industry adaptability. The traditional ceramic industry has a complex supply chain and highly fragmented information. Data public goods, by being deeply embedded in industry logic, enable governance to shift from “experience-driven” to “data-driven”.

Fourth, cross-scenario scalability. A mature data public goods can typically be replicated from the ceramics industry to adjacent industries such as glass, construction, and stone, further enhancing the economies of scale and scope of data elements.

The data public goods mechanism addresses the third research question: How can data public goods evolve into public goods for the ceramics industry and enhance governance capabilities?

Its core values include:

- (1) Enhance corporate credit rating;
- (2) Improve government regulatory efficiency and tax transparency;
- (3) Improve the risk control capabilities of financial institutions and promote capital flow;
- (4) Enhance industry transparency and compliance;

(5) Reduce the cost of public governance at the industry level.

By making data public goods, data elements are transformed from “raw materials” into “governance tools” and from “corporate assets” into “industry public goods,” thereby achieving a profound reshaping of the traditional industrial chain governance structure.

### **3.4 The overall logic of the three mechanisms: from data structuring to supply chain governance restructuring**

In response to the research questions raised earlier, the three-mechanism model constructed in this chapter has a complete logical progression:

(1) Data standardization answers the question of “how data can have an effect”. By reducing transaction costs, improving authenticity, and establishing an industry-level credit system, data can become a reliable means of production.

(2) Platform-based collaboration answers the question of “how a platform becomes infrastructure”. Through data sharing, real-time interaction and algorithm governance, collaborative methods are reconstructed to achieve efficient resource allocation.

(3) Data public goods, answering the question of “how data can improve governance capabilities”. By making data public goods, industry governance tools are provided, making data elements an industry-level public good.

The three mechanisms work together to transform traditional industries from “experience-driven” to “data-driven” and from “decentralized governance structure” to “platform-based collaborative structure,” thereby achieving systemic industrial upgrading.

## **4.Contextual Analysis of Foshan Ceramic Industry**

### **4.1 Context of Digital Transformation in Foshan Ceramics**

Foshan, as one of the core industrial clusters of China’s ceramics industry, has formed a highly complete industrial chain system since the reform and opening up. However, the inherent problems of the traditional ceramics industry, such as long chains, numerous participants, fragmented data, and inconsistent standards, continue to constrain the industry’s efficiency and governance capabilities. The structural pain points long faced by the ceramics industry, such as information opacity, difficulty in verifying the authenticity of transactions, isolated logistics data, weak corporate credit, and difficulties in financial risk control, are highly compatible with the “ownership-circulation-application” system of data elements. Problems such as the separation of invoices and cash flow in raw material transactions, untraceable logistics nodes, and the inability to present production processes in real time significantly restrict ceramic enterprises in tax payment, financing, and supply chain collaboration. For example, different enterprises have different data formats and business standards, resulting in a lack of a unified “real data language” in the industry; regulatory authorities struggle to obtain continuous and traceable data chains; financial institutions find it difficult to identify the true operating conditions of ceramic enterprises, leading to a long-term weakening of the financing structure; and supply chain collaboration relies more on experience, personal relationships, and reputation, making it difficult to form efficient and transparent chain governance.

Against this backdrop, Foshan’s “data elements × ceramics industry” practice is not solely driven by government initiatives, but rather a two-way resonance between “institutional supply” and “industry demand.” On the one hand, policies have established institutional guarantees for the ceramics industry by clarifying data standards, promoting the construction of industry data platforms, and encouraging the compliant listing of data public goods on exchanges. On the other hand, due to operational pressures and intensified competition, companies in the industrial chain urgently need to reduce transaction costs, strengthen credit foundations, and improve collaborative efficiency through data, thereby breaking away from the old model of “capacity competition—low-price competition.” Under this dual impetus, the digitalization process of Foshan’s ceramics industry has shifted from the past “small-scale digitalization” where companies operated independently to a systematic, platform-based, and institutionalized transformation, laying the foundation for the subsequent formation of industry-level data public goods and governance structure reforms.

Overall, the digital landscape of Foshan’s ceramics industry exhibits three significant characteristics: First, the transformation is strongly linked to the “policy-market,” driven by both industrial policies and enterprise needs; second, data elements are no

longer limited to internal enterprise management but are extending to external scenarios such as supply chain collaboration, regulatory governance, and financial services; and third, policies, platforms, and enterprises have formed a tiered evolutionary path of “institutional environment—technology platform—application scenario,” providing the ceramics industry with the basic conditions for developing a digital industrial ecosystem.

#### **4.2 The Formation Logic of the Trustworthy Data Foundation for the Ceramic Industry**

Zhongtaolian Supply Chain Company was the first in the ceramics industry to propose a “scenario—standard—technology—data” framework. Its essence is to take the deep pain points of the industry as the entry point, take data standardization as the core technology, and achieve data credibility through a variety of technologies, ultimately forming an industry-level data foundation.

First, scenario-driven approaches are a key breakthrough in data collection. The complexity of the ceramic industry chain dictates that data cannot be systematically collected through administrative orders or voluntary action by enterprises. It must rely on actual business scenarios, embedding data processes into enterprises’ “strong demand points.” For example, the lack of credible evidence chains for verifying the authenticity of raw material transactions forces the creation of “tax payment assistance scenarios”; frequent changes in logistics and transportation nodes necessitate “logistics visualization scenarios”; the weak credit of small and medium-sized ceramic enterprises drives the development of “supply chain finance risk model scenarios”; and the high cost and insufficient credibility of product quality certification fosters “credible quality certification scenarios.” These scenarios constitute the data entry points of the ceramic industry chain, making data collection a natural by-product of enterprise operations.

Secondly, the standardization system has solved the fundamental problems of “data silos” and “system fragmentation” in the ceramics industry. The industry operation standards and data format standards developed by Zhongtaolian Supply Chain Company enable cross-entity mutual recognition of data such as contracts, logistics, invoices, payments, and production processes among different enterprises. For example, a series of standards, such as “raw material specification data standards,” “logistics node timestamp standards,” “transaction contract format standards,” and “platform data interface standards,” transform the multi-source heterogeneous data generated daily by ceramic enterprises into structured and fusionable data assets. This step is of great significance for industry governance because only by achieving “data comparability, verifiability, and traceability” through standardization can the ceramics industry chain move from experience-based governance to data-based governance.

Secondly, the technological system ensures that the data is “credible, accurate, and verifiable.” The ceramic industry chain has long faced risks of data falsification and data gaps; therefore, simply collecting and standardizing data cannot meet the industry’s demand for trust. Zhongtaolian Supply Chain Company uses technologies such as AI cross-validation, blockchain notarization, and trusted computing to link and compare the flow of goods, funds, invoices, and information. For example, the system automatically issues warnings when waybill data and logistics tracks are inconsistent; it triggers anomaly detection when payment vouchers do not match contract amounts; and it forms a “risk warning chain” when the invoice issuance time and logistics information are completely mismatched. These technologies construct the core “trustworthy data chain” for the ceramic industry.

Ultimately, the 2.2 billion multi-dimensional industry data points accumulated by 2024 formed the ceramics industry’s “largest data foundation.” This data foundation is not simply a collection of data, but rather “high-quality data assets” processed through standardization, verification, and systematization, covering information across the entire supply chain, including supply, logistics, production, and finance. This data not only supports enterprises’ digital operations but also provides a systematic data foundation for supply chain collaboration, tax verification, financial credit, and industry regulation, achieving a fundamental leap from “enterprise data” to “industry data.”

From policy guidance to scenario-driven development, from standards systems to technology verification, and from data collection to data assetization, Foshan’s ceramics industry has successfully built a leading industry-level data foundation in China, providing strong support for upgrading industry governance models and resource allocation methods.

#### **4.3 The formation of the public goods system in the ceramics industry**

Based on a trusted data foundation, the biggest breakthrough for Foshan's ceramics industry lies not in the improvement of enterprises' digital management level, but in the successful evolution of data public goods into industry public goods, which significantly enhances the industry's governance capabilities and reflects the practical application of the "data public goods supply mechanism" proposed in Chapter 3.

One of the most representative institutional innovations in the ceramics industry is the "Transaction Evidence Chain Certificate." In traditional ceramic raw material transactions, tax authorities struggle to ascertain the true nature of transactions, and enterprises lack the incentive for passive compliance. Difficulties in tax payment, verification, and traceability have long plagued both tax authorities and businesses. The Evidence Chain Certificate, as the first data public goods in the building ceramics industry nationwide, integrates a "four-flow-in-one" data chain, AI-powered automatic verification, and blockchain evidence storage mechanisms to form a "data certificate" that can be used for tax audits, compliance verification, and business proof. Its institutional significance lies in transforming data that was originally internal to enterprises into a governance tool that the government can accept, thus becoming an industry public good. Data from the Foshan Municipal Government Service and Data Management Bureau in 2024 shows that this product has served over 1,200 enterprises, supported over 10,000 transactions, assisted in tax payment exceeding 800 million yuan, and has been replicated in 18 industries, including glass and building materials, becoming a typical example of the diffusion of data public goods.

In the financial services sector, ceramic enterprises have long faced problems such as weak credit, high financing costs, and difficulty in obtaining financing. Zhongtaolian Supply Chain Company has built a "behavioral credit system" for enterprises by accumulating real transaction chain data. Financial institutions no longer rely solely on reports and collateral during the credit granting process, but rather on the actual performance and operational data generated by enterprises on the platform. Thanks to this data public goods, the ceramic industry has achieved a breakthrough in financing improvements: 264 enterprises have obtained financing exceeding 1.633 billion yuan, financing costs have decreased by 18.79%, post-loan risk warnings have been issued 30 days earlier, bank customer acquisition efficiency has increased by 46.67%, and loan matching accuracy has improved to 89.47%. This process demonstrates the value of data public goods as a public good: it not only serves individual enterprises but also changes the financing ecosystem of the entire industry.

On the product side, the "Trusted Quality Certificate" provides a digital upgrade path for quality certification in the ceramics industry. Previously, ceramic product certification was costly, time-consuming, and lacked credibility, hindering its effective entry into public procurement and high-end markets. By storing production processes and testing indicators on the blockchain, the Trusted Quality Certificate becomes a quality identifier that customers, regulatory agencies, and the market can trust, making ceramic product quality certification more transparent and reliable. To date, over 300 related data asset transactions have been completed, marking the official entry of the ceramics industry's quality certification system into the data-driven era.

Overall, the data public goods in Foshan's ceramics industry exhibit clear characteristics of public goods:

- (1) Replicability: low marginal cost and rapid scalability;
- (2) Reusability: It can be shared and coordinated across multiple scenarios and departments;
- (3) Public governance effect: It fosters cross-departmental collaboration among taxation, finance, and regulation;
- (4) Industry spillover: It can be replicated and promoted to other industries;

Through the institutionalized application of data public goods, the ceramics industry has achieved a leap from "corporate tools" to "industry public goods," promoting the upgrading of industry governance from "point-based governance" to "platform-based collaboration" and "data governance."

#### **4.4 Data-driven supply chain collaborative upgrading**

Data from the Foshan Municipal Government Service and Data Management Bureau shows that the application of data elements in the ceramic industry chain has gone beyond single-point innovation and is forming a "multiplier effect" through multi-scenario linkage—that is, data is used for reuse, linkage and penetration of multiple links to achieve a leap in the overall collaborative efficiency of the industry chain.

In supply chain management, data platforms enable real-time sharing of previously fragmented information such as demand,

capacity, and logistics, shifting supply and demand matching from reactive to proactive forecasting. For example, the logistics map update cycle has been shortened from the traditional 90–180 days to only 7–15 days, and data collection costs have been reduced to 10% of the traditional model, significantly improving the forecasting accuracy of raw material supply and production plans.

In terms of production management, the traditional production processes in the ceramics industry are slow to respond to logistics and order information, leading to imbalances in production scheduling and inventory backlogs. Through data platform-based chain visualization, companies can monitor upstream and downstream nodes in real time, achieving more precise production scheduling and inventory management, reducing waste and delays.

In terms of industry regulation, the data chain constructs a true, complete, and traceable industry profile, enabling regulatory authorities to shift from traditional “post-event review” to “pre-event warning and real-time supervision.” Tax, market supervision, and industry and information technology departments can obtain real-time data through the platform, significantly reducing verification costs and improving regulatory efficiency and governance accuracy.

From the perspective of the overall effect of supply chain collaboration, the Foshan ceramics industry has achieved a structural upgrade from “experience-based collaboration” to “data-driven collaboration.” This process has not only improved supply chain efficiency but also changed the industry’s governance structure, gradually leading to the following characteristics in the supply chain:

- (1) The collaborative approach has shifted from interpersonal collaboration to data collaboration;
- (2) Information flow has shifted from opaque to visible and traceable;
- (3) Risk management has shifted from passive response to proactive prediction;
- (4) The operation of the industrial chain has shifted from a linear structure to a network structure;
- (5) The governance subject has shifted from independent government governance to a three-party collaboration between platform, enterprise and government.

This collaborative upgrade is of great significance to the ceramics industry because it not only improves costs and efficiency, but also rebuilds the trust foundation of the industrial chain, providing the ceramics industry with the institutional and data foundation for further digital and intelligent upgrades.

#### **4.5 Systemic Evolution and Governance Leap in the Application of Data Elements in the Ceramic Industry**

In summary, the data element practices of Foshan’s ceramic industry have shown a systematic evolution from data collection, data standardization, data platformization to the supply of data public goods, reflecting a multi-dimensional leap from the technical level, organizational level to the governance level.

First, it has enabled a leap from enterprise-level digitalization to supply chain digitalization. Data is no longer confined to within enterprises but has become a shared production resource across the industry.

Secondly, it has achieved a leap from data silos to standardized and trustworthy data governance. With the help of unified standards and trusted technologies, the ceramics industry has established a reliable data language and trust system for the first time.

Third, it has enabled a leap from information systems to supply chain collaboration platforms. Digital platforms have become the infrastructure for the operation of the supply chain, promoting overall collaboration among supply and demand, logistics, production, finance, and other links.

Fourth, it has achieved a leap from enterprise service tools to industry public goods. Data public goods such as “chain of evidence certificates,” “data credit reports,” and “trustworthy quality certificates” have become public governance tools jointly recognized by governments, financial institutions, and enterprises.

Fifth, it has achieved a leap from improving local efficiency to restructuring governance. Data elements have driven the ceramics industry to move from “experience-based governance” to “data-based governance,” forming a replicable and scalable path for the digital upgrading of traditional industries.

The Foshan ceramics data element practice clearly demonstrates how a traditional industry can achieve systematic upgrading



through standardization, platformization, and public goods development driven by data elements, providing a “ceramics model” that can be learned from for traditional manufacturing industries across the country.

## 5. Upgrading Path of Foshan Ceramic Industry

For traditional manufacturing, digital and data-driven transformation is not only a technological revolution, but also a reshaping of industrial governance structures and development models. The Foshan model of “data elements × ceramics industry” provides an empirical basis, but in order to achieve sustainable and scalable industrial upgrading, it is necessary to promote it through the following four systematic paths.

### 5.1 Standardization-Driven Trusted Data Infrastructure System for the Ceramic Industry

The primary prerequisite for the digitalization of the industrial chain is the reliability, uniformity, and reusability of data. The ceramics industry comprises numerous entities with varying sizes and severely heterogeneous information systems, resulting in inconsistent data formats, semantic discrepancies, and incomparable definitions. This fundamentally hinders the release of the value of data elements. Therefore, the upgrading of Foshan’s ceramics industry must adhere to the principle of “standardization first” and promote the construction of fundamental industry systems.

First, establish a comprehensive data standard system. Focusing on key aspects such as raw material supply, production and manufacturing, logistics and distribution, transaction settlement, and quality inspection, develop unified data format standards, data collection specifications, and data classification and grading systems through government guidance, industry alliances, and leading enterprises. For example, standardizing raw material specifications can improve cross-regional circulation efficiency; standardizing logistics nodes facilitates real-time visualization; and standardizing contract, invoice, and fund flow formats forms the basis for transaction verification.

Second, establish data interface standards and an industry data dictionary. The ceramic industry ecosystem contains numerous heterogeneous systems such as ERP, MES, and WMS. Without a unified interface standard, these systems cannot connect smoothly, creating data silos. By establishing industry API specifications, a unified data tagging system, and a data dictionary, internal enterprise data can be read, accessed, and shared, thereby achieving industry-level data interoperability and mutual recognition.

Third, promote the standardization of regulatory data. The government’s data needs in areas such as tax supervision, environmental protection supervision, and quality supervision heavily rely on real data from enterprises. Establishing unified regulatory data standards can reduce compliance costs for enterprises, improve regulatory efficiency, and enable regulatory authorities to utilize accumulated enterprise data for intelligent supervision.

Overall, the significance of standardization lies not only in the unification at the technical level, but also in building a “trustworthy data foundation “ for the industry through the construction of underlying systems, enabling data elements to flow efficiently within the industrial chain, and providing a solid foundation for subsequent platformization, public goods development, and ecosystem development.

### 5.2 Collaborative Governance Path of Industrial Chain Digital Platform

Based on data standardization, the key to the digital upgrade of the ceramics industry lies in building a unified digital platform for the industrial chain, which enables data from multiple entities to be aggregated, integrated, interacted, and intelligently scheduled, thereby optimizing the overall efficiency of the industrial chain.

First, build an industry-level data aggregation platform. The core of platformization is to form a unified data hub, integrating internal enterprise data, platform-accumulated data, and government and external agency data through data access, data cleansing, and data governance. This platform should cover the entire supply chain, including supply, production, sales, logistics, and finance, becoming a “real-time digital mirror” of industry operations.

Second, develop an intelligent industrial scheduling system. Based on the data resources centrally accumulated on the platform, the efficiency of supply and demand matching, production planning and scheduling capabilities, and resource allocation levels in the ceramics industry can be improved through algorithm optimization, intelligent forecasting, and real-time scheduling tools. For example, by analyzing real-time data from logistics nodes, the platform can assist enterprises in optimizing transportation routes; by forecasting capacity load, the platform can provide enterprises with intelligent production



scheduling suggestions; and by analyzing market demand data, the industrial chain can respond more quickly to changes in demand.

Third, platform-based collaboration enables multi-stakeholder collaborative governance. The ceramic industry chain involves multiple stakeholders, including raw material suppliers, manufacturers, logistics companies, distributors, banks, and regulatory agencies. Traditional collaboration relies on manual communication, which is inefficient and lacks transparency. Platform-based collaboration, through process digitization, access control, and data visualization, enables collaboration to occur automatically based on data, building a “digital governance consensus” within the industry. For example, the government can monitor the industry’s operational status in real time; banks can conduct risk control based on platform data; and transparent collaboration can be achieved between enterprises.

Fourth, the platform serves as governance infrastructure, not a standalone system. Foshan’s experience demonstrates that platformization should not be understood as an upgrade of enterprise-level information systems, but rather as a reconstruction of the infrastructure of the industrial governance system. Industry-level platforms are the core carriers for data elements to exert a multiplier effect, enabling industries to shift from “enterprise-driven” to “platform-driven,” and from “point-based digitization” to “networked digitization.”

In summary, platform-based empowerment is a key step for the ceramics industry to transition from traditional manufacturing to a digital governance system, and a systematic path to enhance the resilience, efficiency, and transparency of the industrial chain.

### **5.3 Construction of an Industry Governance System Driven by Data Public Goods**

In practical applications within the ceramics industry, the most groundbreaking innovation is the elevation of data public goods from enterprise-level tools to industry-level public goods, promoting the public governance effect of data elements in areas such as taxation, finance, certification, and regulation through institutional scenarios.

First, creating a public good for tax payment verification data. The ceramics industry has long suffered from opaque raw material transactions and high difficulty in tax verification. Foshan’s practice integrates, verifies, and stores data from four flows (transactions, capital, logistics, and consumer goods) on the blockchain through a “transaction evidence chain certificate,” providing credible evidence to tax authorities. This type of public good not only reduces tax risks for enterprises but also improves the efficiency of regulatory departments, making it a typical “data public goods.”

Second, we need to build a public data goods system for financial services. Ceramic industry enterprises generally lack collateral, making traditional credit rating methods ineffective. The platform provides highly reliable behavioral data such as real transaction data, performance records, logistics tracking, and capital flows, which can serve as important bases for bank credit granting. This enables financial institutions to conduct precise credit granting, intelligent risk control, and dynamic supervision, thereby improving inclusive finance coverage and reducing financing costs.

Third, promote the publicization of quality certification data. Quality certification for ceramic products is costly, complex, and difficult to verify. By storing production process and quality data on the blockchain using credible quality certificates, traceability of quality and credibility of certification can be achieved, thereby enhancing industry reputation and market competitiveness.

Fourth, build a public data system for intelligent regulation. A transparent, authentic, and traceable data chain enables the government to conduct intelligent and real-time industry regulation, reducing regulatory costs, improving regulatory accuracy, and achieving “data-driven regulation.”

The ultimate significance of data public goods lies in: by institutionalizing data public goods, embedding data elements into the industrial governance system, enabling the ceramic industry to achieve structural breakthroughs in key areas such as taxation, finance, certification, and supervision, and promoting the modernization of the governance system.

### **5.4 Building a Sustainable Ecosystem of “Ceramic Industry × Data”**

The ultimate goal of data-driven upgrading of the ceramics industry is to form an open ecosystem that spans industries, regions, and scenarios, enabling the ceramics industry not only to achieve digitalization but also to build future-oriented industrial competitiveness.

First, promote the cross-industry replication of data public goods. Foshan's transaction evidence chain, data credit system, and credible quality certificates have been replicated in industries such as glass and construction, extending from "applications in the ceramics industry" to "public scenarios in the manufacturing industry." In the future, it can be further expanded to the home furnishing, building materials, and engineering industrial chains, realizing the cross-industry diffusion of data public goods.

Second, build a data asset ecosystem for the ceramics industry. Industry data assets formed based on accumulated data can become new capital resources for enterprises. By promoting the market circulation of data through data trading, data services, and data cooperation, the ceramics industry can enter a development stage where "data is the core asset".

Third, promote the deep integration of the "industrial chain, innovation chain, and data chain". Under the ecological model, the ceramic industry not only uses data, but can also form new innovation scenarios around data, such as intelligent quality inspection, product design, personalized production, supply chain forecasting, and green manufacturing, so as to drive the industry towards high quality and high added value.

Fourth, build an open data collaboration network. The future industrial ecosystem needs to have the ability to participate in multiple entities, including governments, platform companies, manufacturing companies, equipment companies, research institutions, and financial institutions, to jointly form a collaborative system for data sharing, value co-creation, and benefit distribution, so as to enable the ceramic industry to have sustainable development capabilities.

The essence of ecological development is to enable the ceramics industry to move from "industrial digitalization" to "digital industrialization," embedding data elements into every link of the industrial value chain to form a new industrial ecosystem that is self-growing, self-circulating, and self-evolving.

## 6. Conclusions and Future Prospects

This paper takes the Foshan ceramics industry as a typical case. Based on an analysis of the national "Data Elements ×" strategy, it constructs a three-mechanism model of "data standardization—collaborative platformization—public goods supply," systematically analyzing how data elements generate governance effects within the traditional manufacturing industry chain, and verifying its operational logic through typical scenarios. The research shows that the impact of data elements on traditional industries has gone beyond the technological dimension and has become a key driving force in reshaping industrial organization, transaction patterns, and governance structures.

Firstly, in the transaction process, data standardization has enabled "credibility," "verifiability," and "circulation" within the industry chain. A unified data standard system has structurally resolved long-standing problems in the traditional ceramics industry, such as opaque raw material transactions, untraceable logistics nodes, and difficulties in comparing invoice information. Data standardization is not merely a technological reform, but also a reconstruction of the industry chain's credit, regulatory, and financial foundations, directly propelling the ceramics industry towards a more institutionalized and standardized operating model.

Secondly, in terms of supply chain collaboration, digital platforms have become a new type of industrial infrastructure. Platform-based governance, through data aggregation, algorithm scheduling, and real-time collaboration, significantly reduces the uncertainty of supply and demand matching, improves the overall efficiency of production-logistics-sales linkage, and transforms the ceramic industry chain from "fragmented enterprise decision-making" to "holistic chain optimization." This model effectively alleviates the persistent problems of information silos, high coordination costs, and severe resource misallocation in the traditional industry chain.

Third, at the industry governance level, data public goods are gradually evolving into public goods, providing institutionalized tools for collaborative governance among governments, financial institutions, and enterprises. Whether it's "transaction evidence chain certificates" improving tax payment supervision, data credit reports promoting inclusive finance, or trusted quality certificates improving product certification efficiency, all these indicate that data public goods have transcended the scope of enterprise services and become industry-wide public governance resources, strengthening industry transparency and compliance.

Overall, the data-driven practices in Foshan's ceramics industry exemplify a typical path for traditional industries to "leap

from point-based innovation to systemic transformation”: establishing a foundation of trust through data standardization, enhancing collaborative capabilities through digital platforms, strengthening industry governance efficiency through the supply of data public goods, and achieving cross-industry replication through ecological development. The research confirms a core viewpoint: the value of data elements lies not in the application of a single technology, but in driving the restructuring of the overall governance structure of traditional industries through the combined effects of systems, platforms, and ecosystems.

The following areas still warrant further research:

First, we need to construct a multi-dimensional quantitative indicator system for the role mechanism of data elements. Although this paper reveals the governance logic of data elements from a mechanistic perspective, the data-driven transformation of traditional industries still requires the support of quantitative models, such as transaction cost indices, collaborative efficiency indices, and data public goods effectiveness indices, to provide a quantitative basis for broader industrial chain research.

Second, conduct comparative studies across industries and regions. The ceramics industry has a highly agglomeration characteristic and a unique chain structure. In the future, it can be compared with traditional industries such as textiles, home appliances, and building materials to verify the external generalizability and boundary conditions of the three-mechanism model.

Third, we need to deepen our research on the interaction between data assetization and industrial finance. Foshan's experience shows that transaction data, performance data, and behavioral credit data can support inclusive finance, but how to price, classify, and regulate data assets in different financial scenarios still needs in-depth discussion.

Fourth, explore incentive and governance mechanisms for data sharing. In traditional industries, companies face competition and data security concerns. In the future, it is necessary to build a more mature data rights and responsibilities system, privacy computing mechanisms, and benefit-sharing mechanisms to encourage more entities to participate in data circulation.

Overall, the digital transformation of Foshan's ceramics industry provides a replicable and scalable practical model for the high-quality development of traditional manufacturing. With the continuous improvement of the data element system, technology system, and market system, data-driven industrial upgrading will have a profound and lasting impact on more industries and more regions.

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# Climate Big Data and Green Financial Asset Pricing ——A Carbon-Sensitive Valuation Model Based on Multi-Source Environmental Data

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**Abstract:** Accelerating global efforts toward carbon neutrality are intensifying climate risks within financial markets. Traditional asset pricing models inadequately incorporate climate-related factors, resulting in systemic undervaluation of green assets. This study develops a Carbon-Sensitive Asset Pricing Model (CS-APM) integrating physical and transition risk factors. We conduct empirical analyses using data from six major economies spanning 2015-2024. Results indicate that singular climate risk factors exhibit positive sensitivity to asset returns. However, simultaneous exposure to dual risks triggers defensive capital reallocation and accelerates impairment of high-carbon assets. Emerging market assets demonstrate consistently positive sensitivity, while developed markets show greater climate risk resilience. Regulatory policy intensity maintains a nonlinear relationship with returns, where technological maturity and policy implementation jointly drive sustainable performance trends in industries. This modeling approach provides a new paradigm for quantifying climate risk premiums and redirecting capital toward climate-resilient sectors.

**Keywords:** Climate Risk; Asset Pricing; Carbon-Sensitive Asset Pricing Models; Green Asset Excess Returns; Machine Learning Optimization

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## 1.Introduction

### 1.1 Research Background and Importance

Driven by the objectives of the Paris Agreement, the global transition toward carbon neutrality is accelerating. Climate risks increasingly impact financial markets, where frequent extreme weather events and specific policy shifts—such as the EU Carbon Border Adjustment Mechanism (CBAM) and Nationally Determined Contributions (NDCs)—persistently cause abnormal asset price volatility. <sup>[1]</sup>Traditional asset pricing models, rooted in the Capital Asset Pricing Model (CAPM), focus on a singular market systemic risk mechanism for asset returns. They inadequately integrate emerging systemic transition risk factors, resulting in systemic undervaluation of green and low-carbon assets—especially those in high-carbon industries. <sup>[2]</sup>Such mispricing reduces resource allocation efficiency and may hinder global climate governance objectives.

Advances in environmental big data offer new solutions. Satellite monitoring, corporate carbon footprint tracking, and extreme weather alerts enable real-time climate risk quantification for assets in financial markets. <sup>[3]</sup> Machine learning's

capabilities in handling unstructured data further reveal nonlinear relationships between carbon emissions and asset returns.<sup>[4]</sup> By integrating these technologies with financial data, this research develops key analytical tools to precisely map climate risk's nonlinear impacts on asset pricing.

## 1.2 Research Objectives

Based on the performance of green assets in the world's six largest economies (2015-2024), this study develops the Carbon-Sensitive Asset Pricing Model (CS-APM). The model integrates multi-source environmental data with financial time-series data, using machine learning to optimize factor weight calculations. This constructs a dual-factor analysis framework for physical and transition risk transmission mechanisms. It reveals nonlinear climate effects on green assets and provides accurate climate risk premium quantification. Consequently, the framework supports investor asset allocation and promotes orderly financial capital flows toward climate-resilient sectors.

## 1.3 Data Source Description

This study integrates monthly observational data (2015–2024) on climate and financial markets from six major economies, including China and the United States. For climate dimensions, the dataset includes key indicators: atmospheric CO<sub>2</sub> concentration, temperature anomalies, extreme weather frequency, and carbon pricing. Where observational gaps exist, we simulate time-series climate data using historical patterns and current trends to match observed characteristics. For financial dimensions, we analyze three asset classes: green indices, carbon-intensive indices, and risk-free rates. All raw and simulated data underwent rigorous time alignment and standardization, forming a multi-regional, multi-industry panel dataset for robust subsequent modeling.

# 2. Model Construction Approach

## 2.1 Factor Design of the Model

This study expands the traditional three-factor asset pricing model by incorporating Physical Risk Factor (PRF) and Transition Risk Factor (TRF), forming a five-factor system. The PRF quantifies direct natural environmental impacts via temperature anomalies and extreme weather frequency.<sup>[5]</sup> The TRF reflects policy-driven market structural adjustments by analyzing interactions between carbon price fluctuations and emission levels.<sup>[6]</sup> Subsequently, these factors undergo orthogonal processing to derive an integrated climate risk. Based on this integrated climate risk, the ratio between asset excess returns and standardized climate risk factors is further derived as the “climate beta,” serving to measure the sensitivity of individual assets or portfolios to systemic climate risks.<sup>[7]</sup> Additionally, the model employs generalized method of moments (GMM) estimation to uncover potential nonlinear relationships between climate risk and asset returns.

The Carbon-Sensitive Asset Pricing Model integrates the Physical Risk Factor, Transition Risk Factor, and traditional asset pricing factors—Market Benchmark, Size, and Book-to-Market Ratio. Its core equation is:

$$E[R_i] - R_f = \beta_{i,MKT}MKT + \beta_{i,SMB}SMB + \beta_{i,HML}HML + \beta_{i,PRF}PRF + \beta_{i,TRF}TRF + \alpha_i$$

## 2.2 Dynamic Adjustment Framework of the Model

Current fixed-parameter models fail to adapt to rapidly evolving climate policies and markets.<sup>[8]</sup> To address this, our model incorporates a dynamic response mechanism. When major disruptive events occur—such as carbon market rule adjustments or carbon tax introductions—structural discontinuities automatically trigger parameter re-estimation. This enables timely risk premium updates, enhancing model adaptability.

Environmental data complexity also challenges traditional integration methods.<sup>[9]</sup> We therefore apply machine learning to optimize Physical and Transition Risk Factor weightings through time-series cross-validation, achieving more interpretable composite climate risk indicators.<sup>[10]</sup>

To maintain predictive validity in dynamic conditions, the model employs seasonal autoregressive moving average (SARMA) for rolling historical forecasts. Regular backtesting evaluates prediction performance. Collectively, these features ensure effective capture of climate risk-pricing relationships and robust forecasting adaptability.<sup>[11]</sup>

# 3. Factor Loadings Analysis

## 3.1 Significant Climate Risk Premium

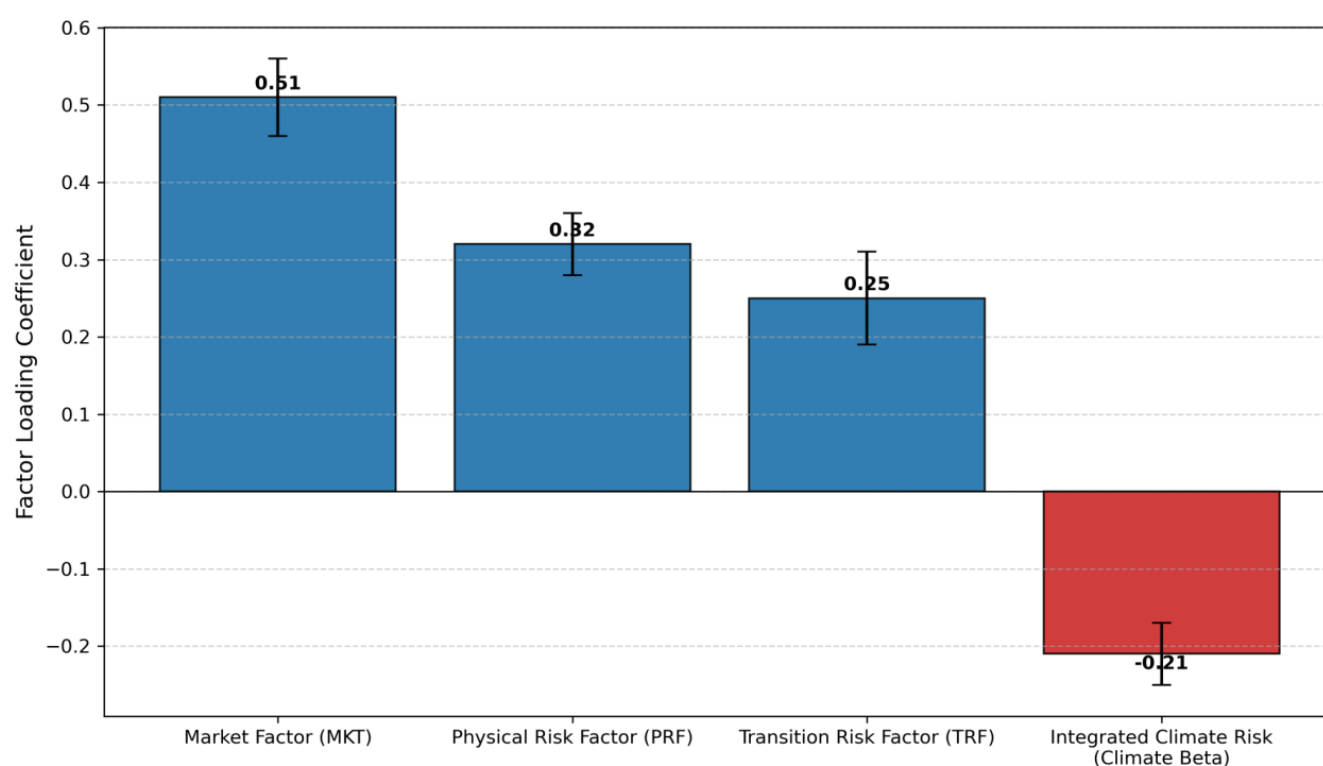


Factor loading estimation reveals significant positive values for both the Physical Risk Factor (PRF=0.32) and Transition Risk Factor (TRF=0.25). This demonstrates that asset risk premiums increase when exposed to isolated physical shocks or policy transition pressures.<sup>[2]</sup> Both factors represent distinct systematic risks: direct physical damage from extreme weather and structural transformation costs from policy changes. These increase corporate operational costs and uncertainty, prompting markets to demand higher compensation through elevated risk premiums. This confirms the pricing role of climate risk factors.

### 3.2 Dual-Channel Transmission in Factor Loadings

When physical and transition risks compound in markets, their combined impact often exceeds the tolerance thresholds of high-carbon, low-resilience assets. This forces accelerated defensive asset reallocation by investors: capital rapidly shifts from highly vulnerable high-carbon assets to green, low-carbon alternatives supported by policies and technological advantages.<sup>[12]</sup> Thus, while individual risk factors increase compensation demands, their combined elevation triggers structural market shifts. These manifest through interactive risk effects that accelerate discounting of vulnerable assets.

Figure 1: Factor Loading Estimates for CS-APM Model



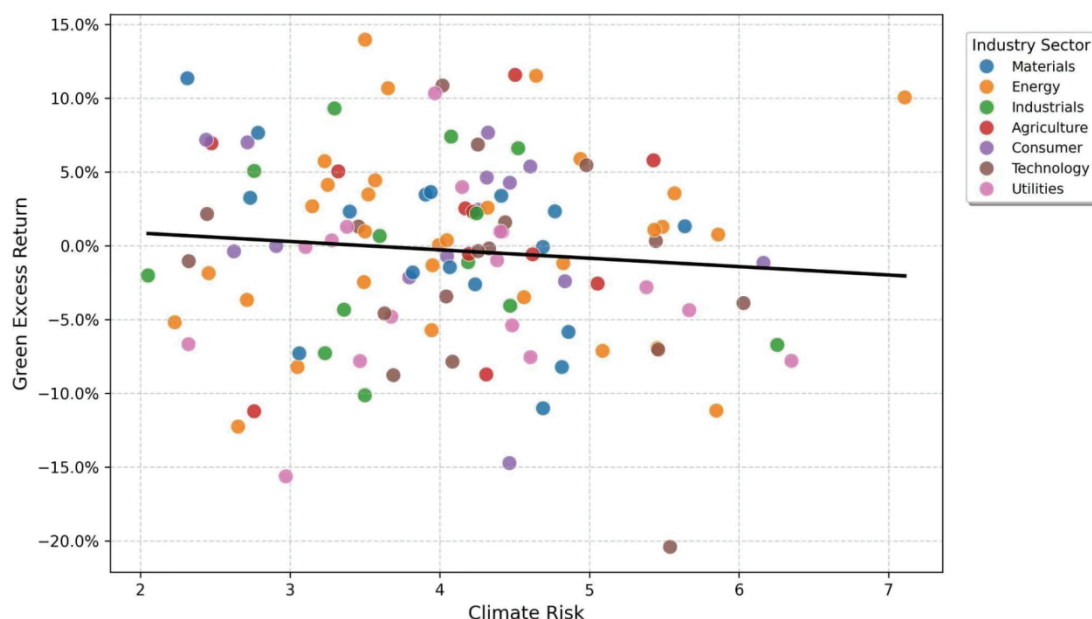
## 4. Heterogeneity in Carbon Excess Returns

### 4.1 Limited Sectoral Correlation with Climate Risk

Industry analysis reveals dispersed data points between climate risk exposure and green asset excess returns, indicating weak linear correlation (Figure 2). Technology sector assets generally yield higher returns across risk levels, while utilities show consistently lower returns. Significant cross-industry data overlap suggests sector attributes are not primary drivers of climate risk pricing.<sup>[13]</sup>

Two factors may explain this dispersion. First, companies facing similar climate risks differ substantially in risk-mitigation capabilities through technological innovation, supply chain resilience, or business model adaptation.<sup>[14]</sup> Second, climate risks' long-term valuation impacts are masked short-term by market volatility, investor sentiment shifts, and non-climate factor noise.<sup>[15]</sup> These effects dilute observable correlations at the industry level, producing non-clustered data distributions.

Figure2: Climate Risk Exposure vs. Green Asset Performance



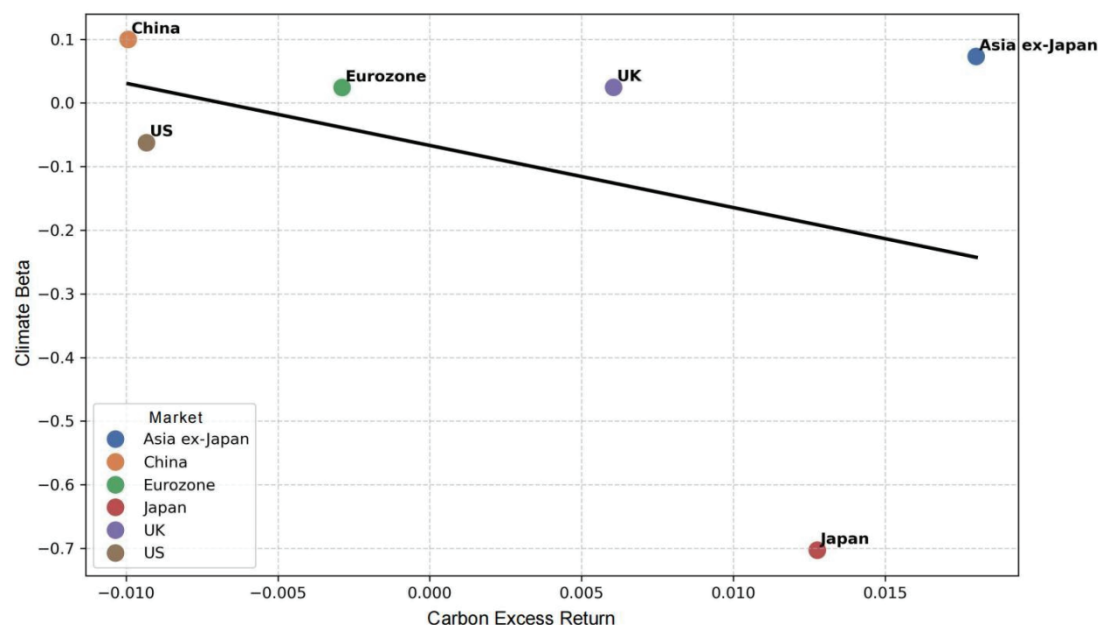
#### 4.2 Regional Disparities in Climate Risk Exposure

Global markets show significant divergence in climate risk response, revealed through a gradient in climate beta distributions. Emerging markets demonstrate positive climate betas, led by China ( $\beta=0.1$ ). Developed markets display predominantly negative betas, with Japan lowest ( $\beta=-0.7$ ). Asia's newly industrialized economies present an intermediate case: they maintain a positive  $\beta=0.08$  climate beta yet generate positive carbon excess returns.

Structural disparities likely drive this regional differentiation. Emerging economies face heightened physical climate risks combined with immature risk-hedging mechanisms.<sup>[16]</sup> These conditions elevate asset climate sensitivity (positive  $\beta$ ) but do not translate to excess returns due to technological/policy limitations; instead, climate pressure constrains returns.

Developed markets absorb risk through advanced infrastructure, mature low-carbon technologies, and robust climate adaptation policies.<sup>[17]</sup> This produces greater resilience (negative  $\beta$ ) alongside stable returns supported by sophisticated markets. Asia ex-Japan's industrializing economies achieve balance via superior technology assimilation and supply-chain modernization. These efficiency gains enable moderate climate sensitivity while sustaining positive returns through enhanced competitiveness.

Figure3: Climate Beta Estimate Rollups across Markets



## 5. Climate Policy-Investment Returns Nexus

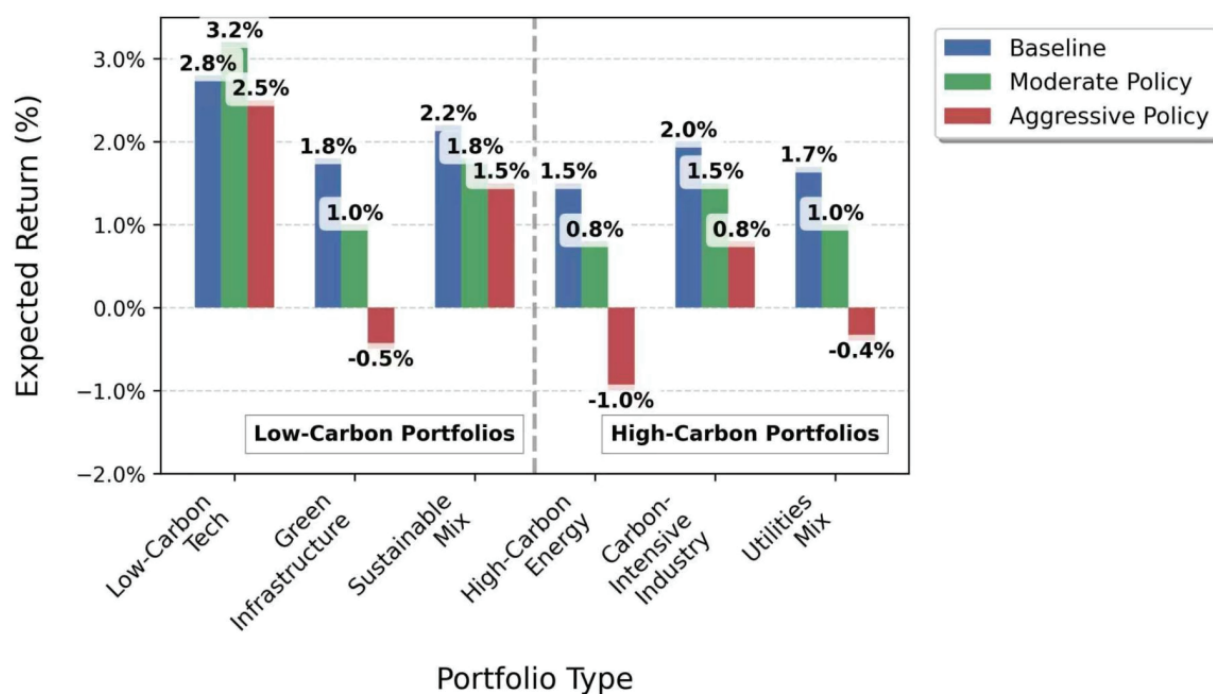
### 5.1 Policy Intensity as Return Driver

This study continues to investigate diversified portfolio returns under varying carbon policy intensities, revealing dynamic policy-market interactions. Figure 4 shows expected return patterns across six portfolios under three policy scenarios: lenient, moderate, and aggressive.

Under baseline conditions, the low-carbon technology portfolio delivers the strongest returns (2.8%). High-carbon energy (1.5%) and utilities (1.7%) portfolios lag. Moderate policy tightening triggers divergence: low-carbon portfolios retain advantage while high-carbon options decline significantly. Aggressive policies widen disparities dramatically—the low-carbon portfolio outperforms, whereas high-carbon energy plummets to -1.0% and utilities to -0.4%. Crucially, policy-inflicted losses on high-carbon assets accelerate nonlinearly beyond specific intensity thresholds. This accelerating decline contrasts with low-carbon assets' linear policy benefits.

This divergence originates in carbon cost transfer efficiency variations. Low-carbon portfolios leverage technological advantages to hedge policy shocks, enhancing returns.<sup>[18]</sup> High-carbon assets conversely face mandatory carbon cost internalization. Their diminishing ability to pass costs downstream vanishes entirely under aggressive policies.<sup>[19]</sup>

Figure 4: Impact of Carbon Policy Scenarios on Diversified Portfolios

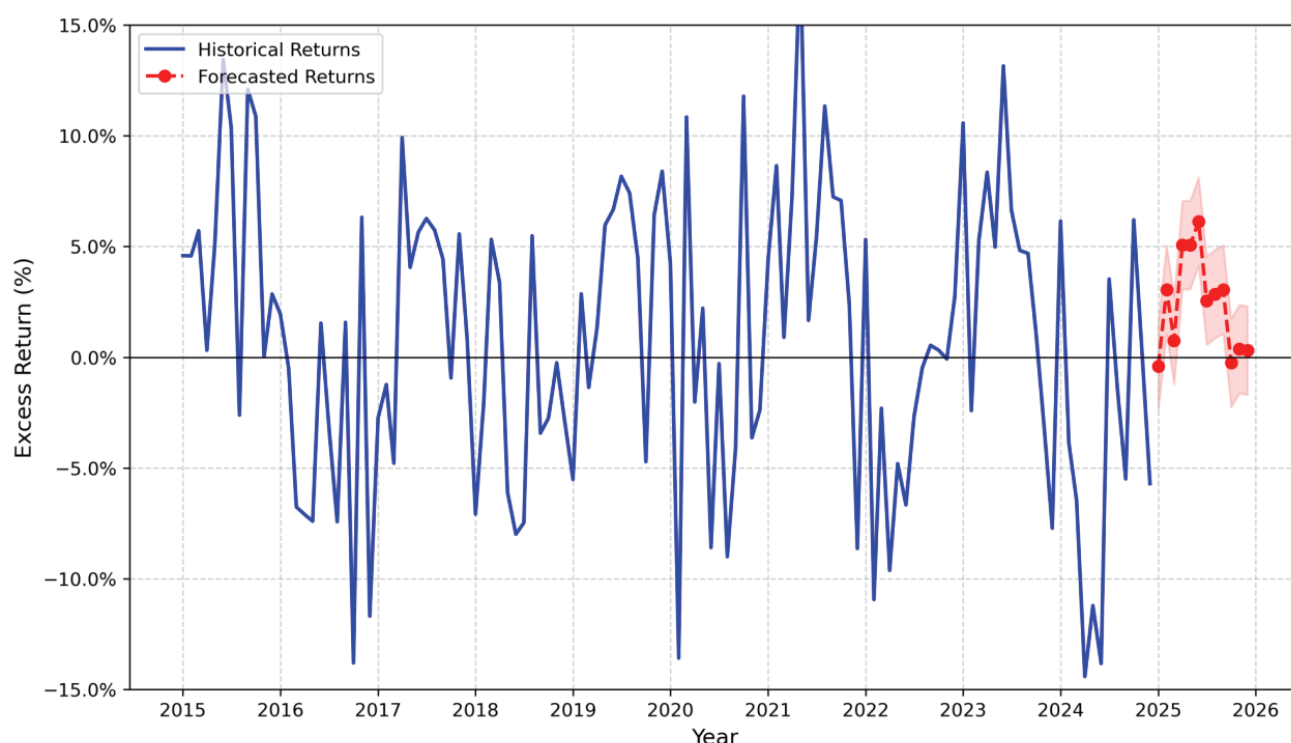


### 5.2 Policy Orientation Effects on Projections

Figure 5 tracks the dynamic evolution of green asset excess returns through historical fluctuations and model projections. Historical data identifies sharp negative dips reaching -0.14% during 2017 and 2020. The projection however indicates a pivotal shift: from 2024 onward, green asset returns will enter sustained growth, surpassing recent peaks to reach approximately 0.05% by 2025.

This transition from volatility to growth stems from strengthened policy guidance and accumulated market learning.<sup>[20]</sup> Historical volatility episodes reflect transient market mispricing during policy signal adjustments or external shocks—exemplified by the pandemic-driven 2020 downturn.<sup>[21]</sup> This demonstrates how major international climate initiatives steadied market expectations. Concurrently, ongoing green technology maturation generates significant scale economies and cost reductions, dampening policy disruption impacts and establishing a clear upward return trajectory.<sup>[22]</sup>

Figure5: Green Asset Excess Returns Forecast(2015-2025)



## Conclusion

Overall, Physical and transition climate risks now systematically influence asset pricing. Their positive loadings confirm that markets incorporate climate shocks into valuations.<sup>[23]</sup> This necessitates updates to financial theories and investment practices. First, investors must integrate climate risk into asset allocation frameworks by establishing dynamic climate beta monitoring. <sup>[24]</sup>Jennifer</author><author>Bridges, Todd Arthur</author><author>Shah, Kushal</author></authors></contributor><titles><title>Reinventing climate investing: building equity portfolios for climate risk mitigation and adaptation</title><secondary-title>Journal of Sustainable Finance & Investment</secondary-title></titles><periodical><full-title>Journal of Sustainable Finance & Investment</full-title></periodical><pages>191-213</pages><volume>9</volume><number>3</number><dates><year>2019</year></dates><isbn>2043-0795</isbn><urls></urls></record></Cite></EndNote>Assets with high climate beta require explicit risk premium compensation. Second, dynamic portfolio rebalancing should respond to policy shifts. When carbon prices breach critical thresholds or policies change structurally, carbon-intensive holdings must be adjusted. <sup>[25]</sup>Financial institutions should develop climate resilience indices integrating Physical Risk Factors (PRF) and Transition Risk Factors (TRF). These instruments will enable more efficient capital allocation toward low-carbon technologies and climate-resilient sectors.<sup>[26]</sup>

While the Climate Stress-Asset Pricing Model (CS-APM) effectively captures climate risk transmission channels through its dual-factor design, limited corporate carbon footprint data reduces its micro-level precision. Future research could enhance accuracy through granular carbon tracking technologies. The model also omits geopolitical factors despite their moderating effect on climate risk transmission. Future studies should therefore incorporate geopolitical risk indices to support climate-smart investment strategies.

## Funding

No

## Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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# Portfolio Risk Management: An Empirical Study Based on ARIMA and Random Forest

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**Abstract:** This study proposes a hybrid framework for portfolio risk management in the Chinese A-share market, combining diagnostics-driven ARIMA identification with Random Forest based feature integration under a Value-at-Risk (VaR) optimization scheme. Unlike conventional parametric VaR models that depend on restrictive distributional assumptions, the framework separates mean dynamics from residual volatility and incorporates nonlinear predictors, including momentum, realized volatility, and higher-order moments. By extending prior ARIMA-machine learning hybrids, which have primarily focused on return forecasting and mean-variance allocation, this study advances the methodology through direct quantile estimation and its integration into a VaR-constrained portfolio decision process. Empirical evidence indicates that the proposed framework generates more accurate VaR forecasts, stabilizes portfolio volatility, and enhances backtesting performance relative to equal-weighted and benchmark strategies.

**Keywords:** Portfolio Risk Management; ARIMA; Random Forest; Value-at-Risk; Chinese A-share Market; Machine Learning; Time Series Forecasting

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## 1.Introduction

In the context of increasingly complex and volatile Chinese financial markets, managing risk behavior has become a central issue in portfolio research. The classical mean-variance framework proposed by Markowitz laid the foundation for portfolio optimization, but its underlying assumptions are often violated in practice<sup>[1]</sup>. Empirical studies have shown that stock return series frequently exhibit nonstationary behavior, which limits the effectiveness of traditional static models in accurately capturing market risk<sup>[2,3]</sup>.

The development of time series analysis and machine learning methods has provided new tools for financial risk modeling. The autoregressive integrated moving average (ARIMA) model is effective in capturing linear dependence and trend components of returns. Machine learning models, particularly random forest, demonstrate strong ability to handle nonlinear dynamics and long-term dependencies. The integration of these methods can combine the strength of mean forecasting with volatility prediction, thereby improving the accuracy of risk measures such as Value-at-Risk (VaR)<sup>[4]</sup>.

Existing literature has largely focused on the performance comparison of individual models<sup>[5,6]</sup>, or has been limited to data from developed markets<sup>[7]</sup>. There remains a lack of systematic research on constructing hybrid models that combine linear and nonlinear characteristics in emerging markets such as the Chinese A-share market. Moreover, the practical application

of VaR models continues to face challenges related to exceedance rates and risk clustering, which calls for more flexible modeling strategies.

This study proposes a portfolio risk management framework that integrates ARIMA and Random Forest models. Specifically, ARIMA is employed to capture the mean dynamics of portfolio returns, while Random Forest is applied to predict portfolio volatility. The combined forecasts are used to compute risk measures including Value-at-Risk. Through empirical analysis, this paper not only compares the performance of different models but also employs backtesting methods such as the Kupiec test and the Christoffersen test to evaluate their validity. The findings aim to provide investors and risk managers with a more accurate and practical approach to risk control.

This study contributes in three ways. First, it combines ARIMA and Random Forest models to capture both mean dynamics and nonlinear volatility, overcoming the limits of using a single method. Second, it applies this hybrid approach to the Chinese A-share market with overlay mechanisms, where VaR and ES estimates guide exposure scaling and volatility targeting for practical risk control. Third, it validates the framework through Kupiec and Christoffersen backtests, ensuring that tail-risk forecasts are statistically reliable. Together, these contributions provide one of the first integrated approaches to portfolio risk management tailored to emerging markets.

## 2.Literature Review

Current research on forecasting Value-at-Risk (VaR) in the Chinese A-share market has mainly focused on parametric and semi-parametric approaches, particularly those based on the GARCH family of models and Extreme Value Theory (EVT). For example, Du, Tang & Li combine a GARCH model with a Peak-Over-Threshold (POT) EVT component to better capture thick tails in the distribution of returns for Shanghai and Shenzhen indices. Similarly, Wang demonstrates that GARCH (1,1) models with Student's t-distributions tend to outperform normal-error versions in forecasting Chinese stock market volatility<sup>[8]</sup>. More recently, Song & Li propose a score-driven parametric model using a Normal Inverse Gaussian distribution (NIG-DCS-VaR), which outperforms the realized GARCH (RGARCH) models in terms of coverage and independence of VaR violations<sup>[9]</sup>.

Early applications of GARCH-based VaR in the Chinese mainland stock market highlight both the potential and the limitations of parametric methods. While most studies of VaR forecasting in the Chinese A-share market have concentrated on index-level risk, a smaller body of research has examined stock portfolios. Zhang applies a GARCH-VaR framework to sectoral portfolios and finds that although parametric approaches capture volatility clustering, they often underestimate extreme tail losses<sup>[10]</sup>. Du, Tang and Li similarly combine GARCH with EVT in portfolio settings, showing that incorporating heavy-tailed distributions improves VaR backtesting performance. However, such portfolio studies largely remain within parametric or semi-parametric frameworks, emphasizing covariance stability and distributional assumptions. There has been little attention to hybrid approaches that combine time-series forecasting with machine learning for portfolio-level VaR estimation<sup>[11]</sup>. This gap motivates the present study, which integrates ARIMA to capture mean dynamics with Random Forest to model volatility and variable interactions, thereby providing a more flexible portfolio risk management framework tailored to the Chinese A-share market.

Parallel to this literature, a growing body of work explores the combination of ARIMA with machine learning models such as Random Forest to enhance predictive accuracy in the Chinese stock market. Cai demonstrates that integrating ARIMA forecasts with Random Forest improves closing-price predictions for individual A-share stocks<sup>[12]</sup>, while Zhao directly compares ARIMA and Random Forest to highlight their respective strengths in capturing linear and nonlinear dynamics. Extensions to portfolio settings also exist: Deng employs ARIMA forecasts for selected A-share stocks and combines them with Monte Carlo simulation in a mean-variance framework<sup>[13]</sup>, while Zheng et al. use LSTM forecasts to optimize CSI300 portfolios under Sharpe-maximizing and minimum-variance objectives<sup>[14]</sup>. Beyond volatility modeling, ARIMA has also been applied in conjunction with mean-variance portfolio theory, providing evidence that traditional time-series forecasts can be directly embedded into allocation frameworks<sup>[15, 16]</sup>. These studies indicate that hybrid modeling, which links time-series methods with machine learning, can enrich price forecasting and portfolio construction. Yet, the focus of all these literatures remains predominantly on return prediction and variance-based optimization, leaving tail-risk metrics such as VaR largely

unaddressed.

This gap motivates the present study. By integrating ARIMA to model the mean dynamics of portfolio returns with Random Forest to capture volatility and nonlinear interactions among risk factors, the framework proposed here moves beyond price forecasting to direct risk quantile estimation. In doing so, it connects price dynamics, portfolio design, and risk measurement in a unified manner. The ARIMA-RF hybrid thus provides a richer basis for forecasting VaR, enabling more accurate assessment of downside exposure in the Chinese A-share market.

### 3. Methodology

The ARIMA  $(p, d, q)$  model is specified as:

$$\Phi(B)(1-B)^d r_t = \Theta(B)\varepsilon_t,$$

where  $\Phi(B)$  and  $\Theta(B)$  are autoregressive and moving-average polynomials, and  $\varepsilon_t$  is white noise.

Random Forest (RF) is applied to the ARIMA residuals to capture nonlinear features and volatility dynamics. Predictor variables include lagged returns, volatility indicators, and macro factors (e.g., VIX, exchange rate). RF outputs the predicted conditional variance  $\widehat{\sigma}_{t+1}^2$ .

The forecasts from ARIMA and RF are combined into a conditional distribution of returns:

$$r_{t+1} \sim \mathcal{N}\left(\widehat{\mu}_{t+1}^{ARIMA}, \widehat{\sigma}_{t+1}^{RF^2}\right)$$

This hybrid ARIMA–RF framework builds on ARIMA’s strength in modeling mean dynamics and RF’s capacity to capture nonlinear volatility patterns.

Based on the conditional distribution, the one-period-ahead VaR at confidence level  $\alpha$  is calculated as:

$$VaR_{\alpha,t+1} = \widehat{\mu}_{t+1} + \widehat{\sigma}_{t+1} Z_\alpha$$

where  $Z_\alpha$  is the quantile of the standard normal distribution.

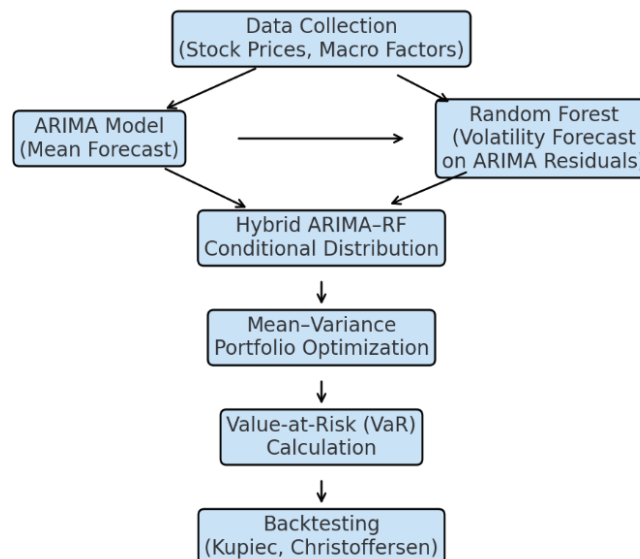
Using the ARIMA-RF forecasts for expected returns and variances, the portfolio weights are determined by solving a mean–variance optimization problem:

$$\min_w w^\top \Sigma w \quad \text{s.t.} \quad w^\top \mu = \mu^*, \mathbf{1}^\top w = 1$$

where  $w$  is the vector of asset weights,  $\Sigma$  is the covariance matrix estimated from RF-predicted volatilities, and  $\mu^*$  is the target expected return. This yields the efficient portfolio with the optimal trade-off between return and risk.

The predicted VaR is evaluated using standard backtesting methods, including the Kupiec test for unconditional coverage and the Christoffersen test for independence of violations, to assess the adequacy of the hybrid ARIMA–RF framework in portfolio risk management. This analytical framework is presented in Figure 1.

Figure.1 Analytical Framework



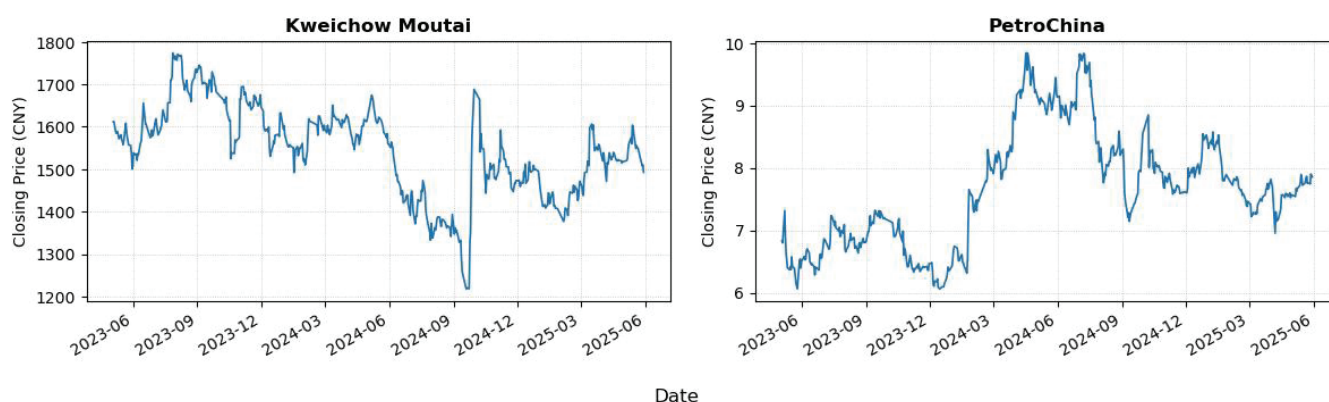
## 4.Data Description

This study employs daily data from the Chinese A-share market, covering the period from May 2023 to May 2025. The portfolio is constructed from two representative stocks selected based on their market capitalization, liquidity, and sector representativeness. These include Kweichow Moutai (600519.SH) from the consumer staples sector and PetroChina (601857.SH) from the energy sector. The rationale for it follows the principle of cross-industry diversification, combining a defensive consumer stock with a cyclical resource stock to balance portfolio stability and volatility. The Shanghai Composite Index (000001.SH) is adopted as the market benchmark. All price data are retrieved from the Baostock platform and are forward adjusted for dividends and stock splits. Daily returns are computed as logarithmic differences of adjusted prices.

## 5.Empirical Analysis

### 5.1 Time-series characteristics and ARIMA identification

Fig 2. Price Time Series



In Figure 2, Kweichow Moutai exhibits relatively stable movements around a long-run mean with episodic corrections, reflecting its defensive consumer profile. In contrast, PetroChina displays stronger cyclical swings, with sharp rises and corrections linked to energy market conditions. These distinct dynamics highlight the stability-volatility trade-off between consumer staples and resource stocks, motivating their joint use in a diversified portfolio and the need for volatility-sensitive modeling.

Figure 3.1. ACF/PACF for Kweichow Moutai

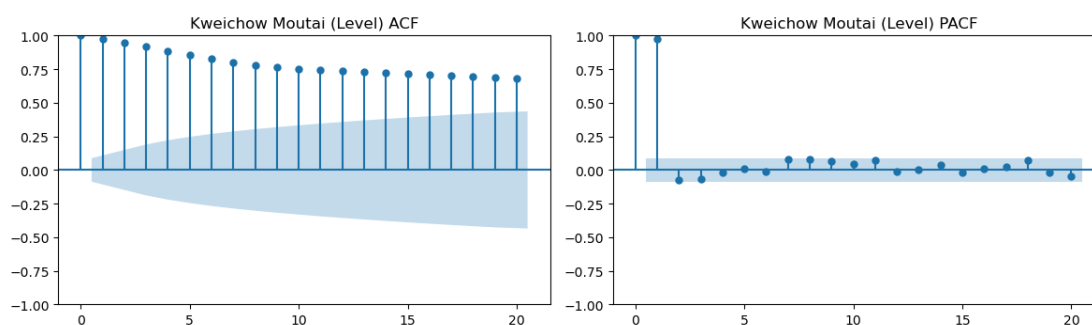
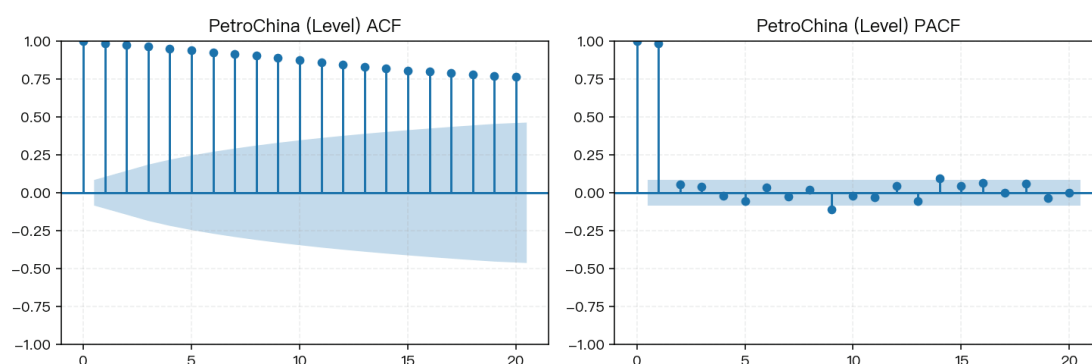


Figure 3.2. ACF/PACF for PetroChina



The ACF and PACF shown in Figure 3.1 and Figure 3.2 indicates that the at level decays for Moutai and PetroChina, slowly from approximately 1 and remains significantly positive across many lags, while PACF shows one or two leading spikes then tapers off. This is the textbook footprint of a non-stationary process, so differencing is required ( $d>0$ ).

After first differencing, as shown in Figure 3.3 and Figure 3.4, ACF/PACF values lie mostly within the confidence bands with only small, short-lived autocorrelations. This supports  $d=1$  as sufficient to achieve stationarity for both stocks.

Figure 3.3. ACF/PACF for Moutai after first differencing

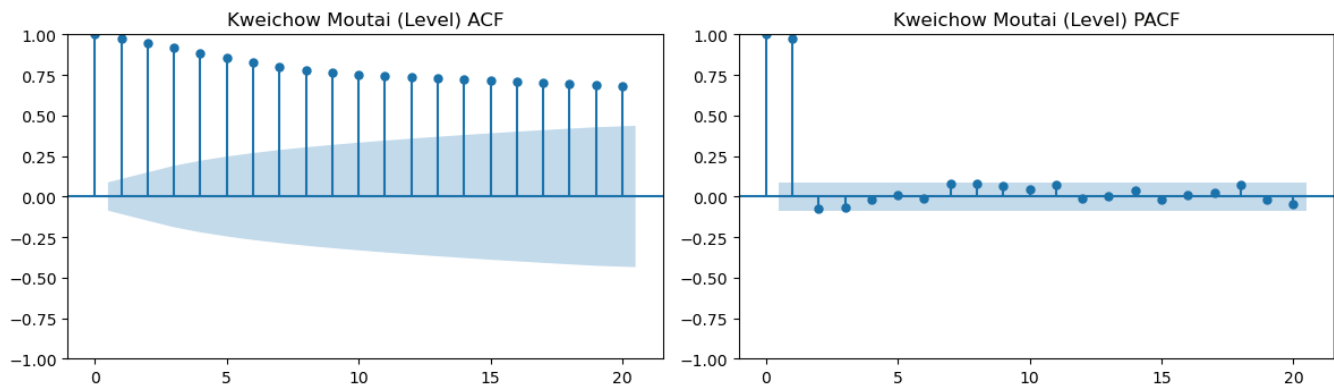


Figure 3.4. ACF/PACF for PetroChina after first differencing

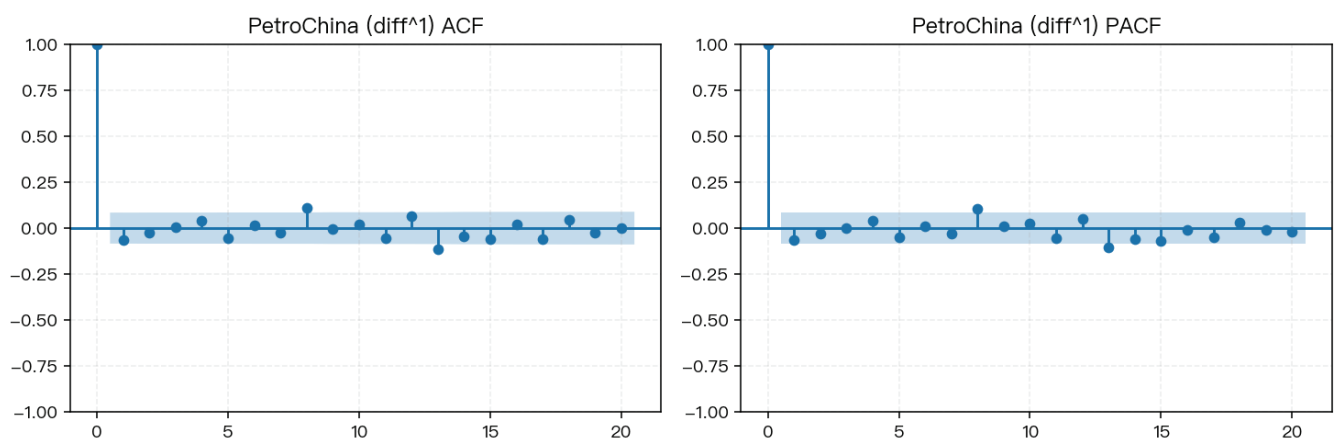
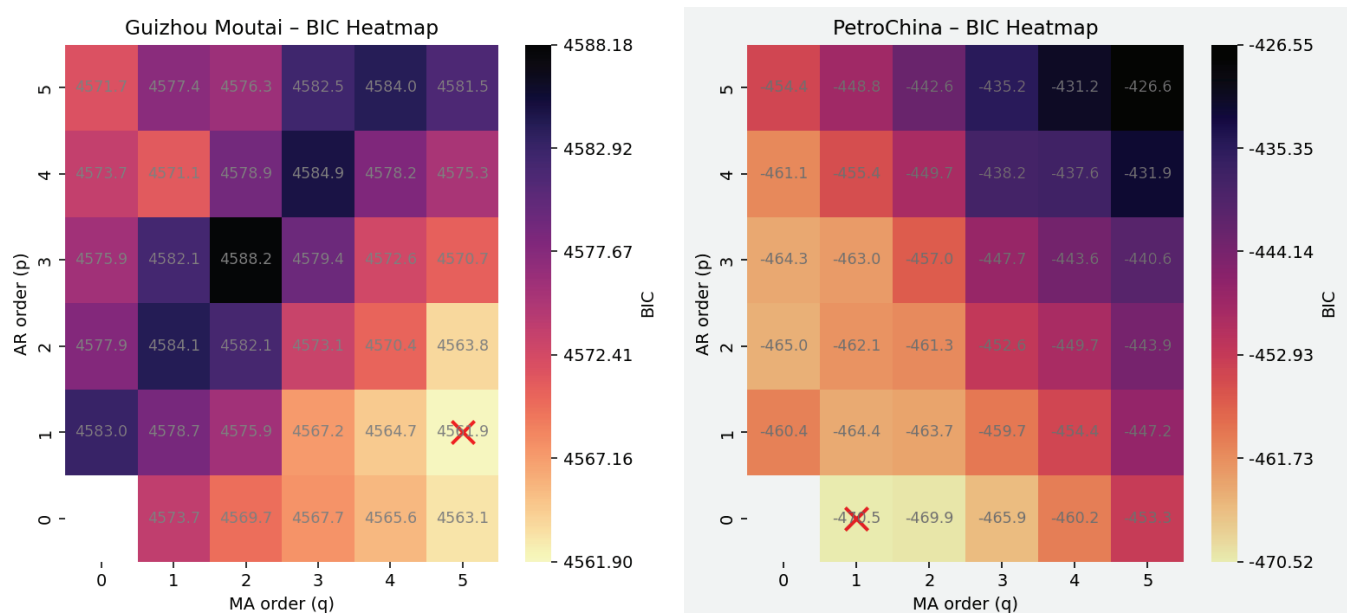


Figure 4. BIC Heatmap( $d=1$ ) for Kweichow Moutai and PetroChina



Using  $d = 1$ , a BIC grid over  $(p, q)$  selects ARIMA(1,1,5) for Kweichow Moutai and ARIMA(0,1,1) for PetroChina; neighboring specifications exhibit higher BIC and are rejected by parsimony. Economically, these choices are consistent with prices that behave like near-random walks, with short-memory MA dynamics capturing transitory shocks and microstructure effects once the unit root is removed. Consequently, one-month forecasts have limited directional drift and tend to revert to the most recent level, while uncertainty widens with horizon.

Figure 5.1. In Sample Fit for Kweichow Moutai

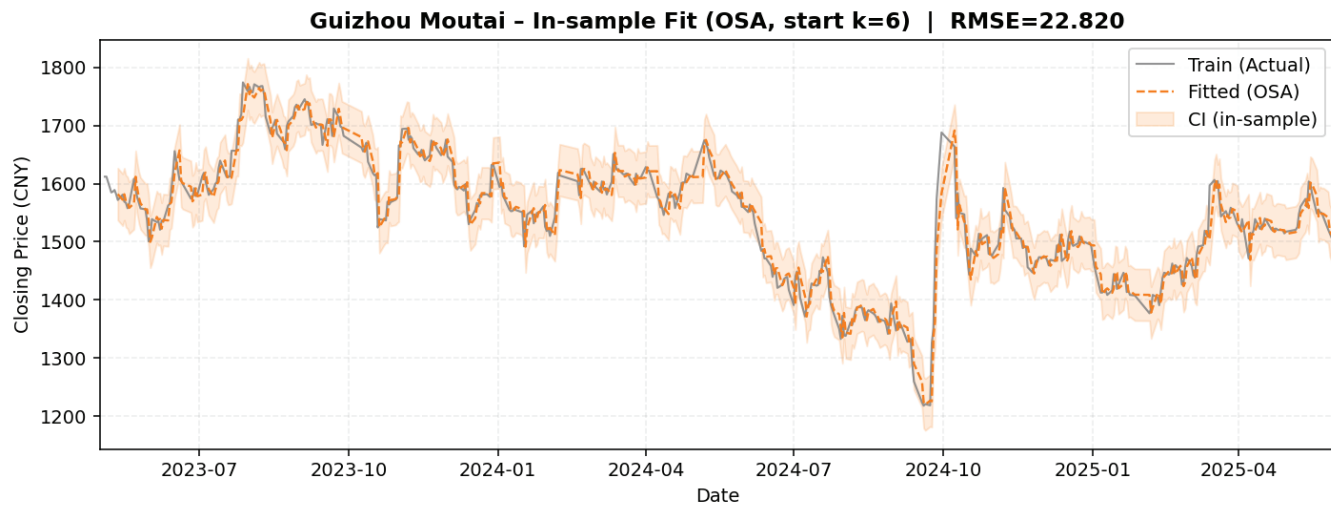
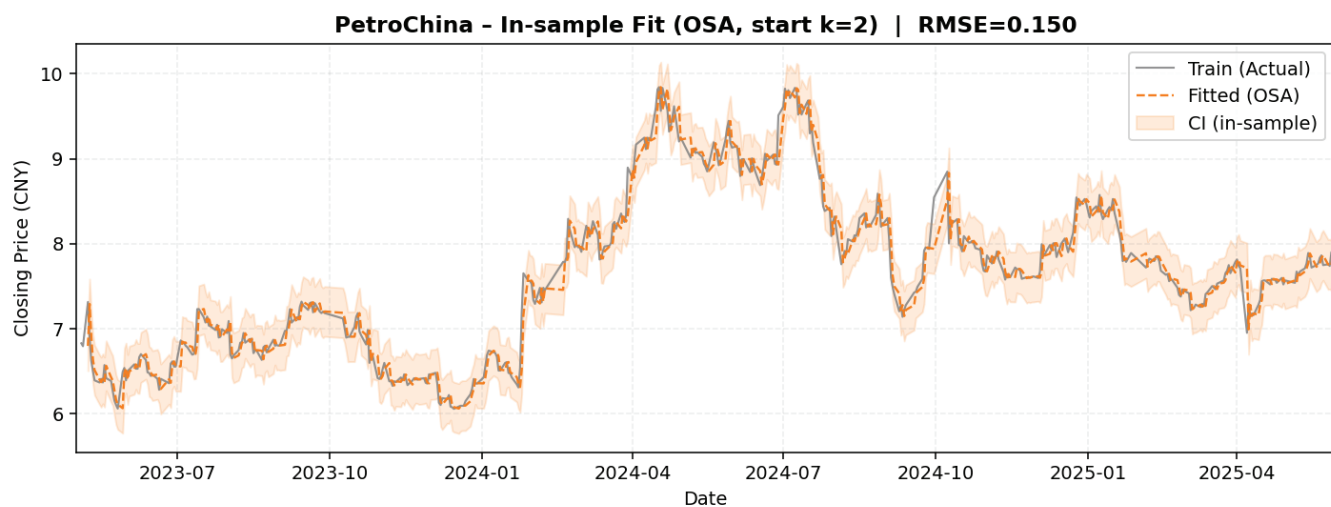


Figure 5.2. In Sample Fit for PetroChina



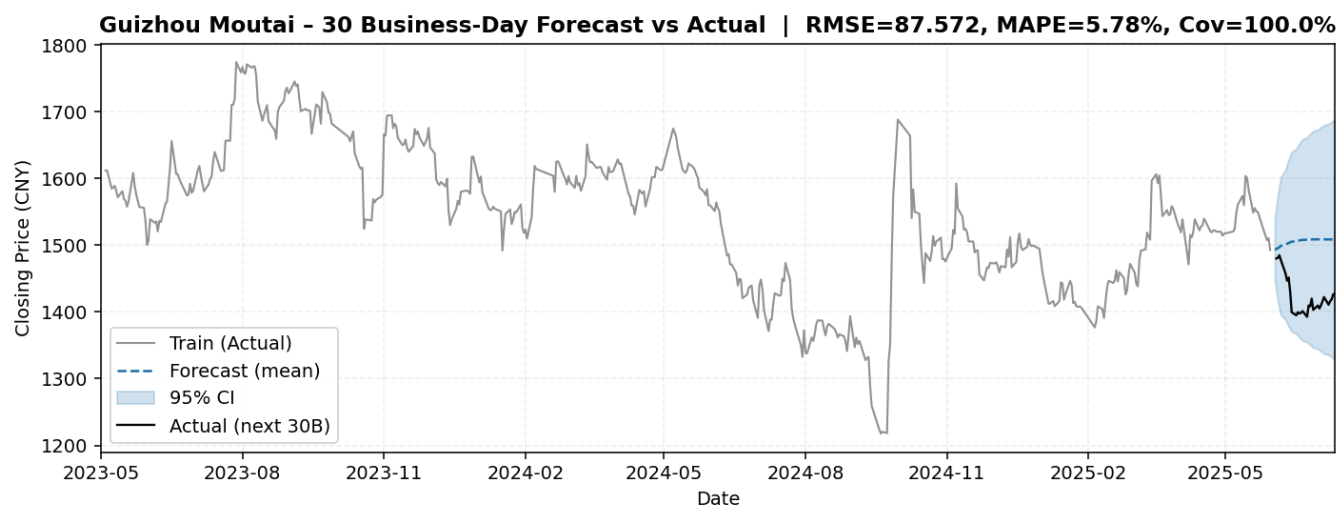
As shown in Figure 5.1 and Figure 5.2, the dynamic one-step-ahead ARIMA fit tracks the low-order mean dynamics without systematic over or under shooting; deviations are mainly around abrupt price jumps rather than sustained bias. The confidence bands widen in volatile episodes and contract in calmer periods, and the residuals are conditionally heteroskedastic, which is an expected feature of equity returns. Overall, the differencing plus low-order MA terms capture short-run structure while avoiding noise-tracking overfit.

## 5.2 Short-horizon forecasts and uncertainty quantification

Figure 6.1 and Figure 6.2 presents the 30-day multi-step forecast and its 95% confidence band from the selected ARIMA. The point forecast extends the local trend, while the confidence interval widens with horizon, reflecting compounding parameter and innovation uncertainty.

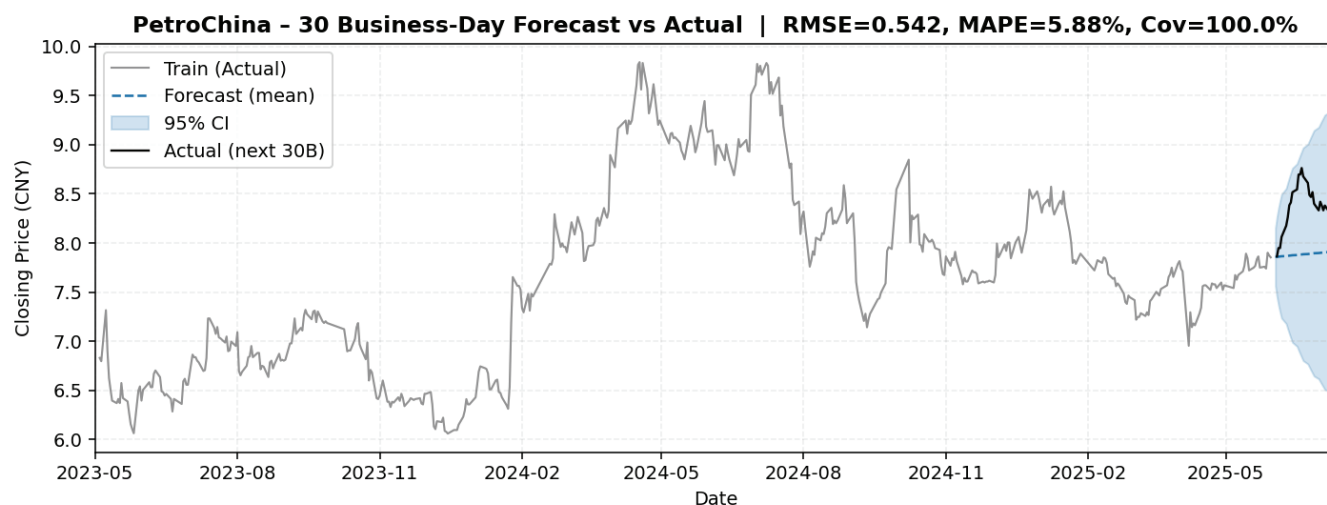


Figure 6.1. Kweichow Moutai - 30-day Closing Price Forecast



In Figure 6.1 (Kweichow Moutai), the one-month-ahead path is nearly flat mean-reverting around the latest level, which is approximately mid-1,500s CNY. The fan-chart widens quickly, indicating that model uncertainty dominates beyond approximately 2 weeks. No persistent drift is detected; the interval comfortably envelops recent volatility.

Figure 6.2. PetroChina - 30-day Closing Price Forecast



In Figure 6.2 (PetroChina), the forecast is essentially level near the current price, which is about CNY 8.2, with a wide, symmetric band that grows over the horizon. This reflects weak directional signal and high conditional variance relative to the level.

In sum, ARIMA fitted on daily closes tends to revert to the last observed mean when trend evidence is weak; predictive intervals therefore fan out with horizon. Both series show limited near-term directional conviction and non-trivial downside risk, so subsequent portfolio results are driven more by risk management (VaR) than by return forecasts.

### 5.3 Cross-sectional predictability: feature relevance

To further assess which variables are most informative for cross-sectional return prediction, the feature relevance extracted from the Random Forest model is examined. The set combines ARIMA-based measures of model uncertainty, higher-moment statistics such as kurtosis and skewness, realized volatility, and price-based signals including momentum and moving-average gaps. These variables are selected because they jointly capture uncertainty, tail risk, volatility persistence, and continuation or reversal dynamics that are theoretically relevant for cross-sectional return prediction.

Fig 7.1. Random Forest Feature Importance for Moutai (1-Month Ahead Return)

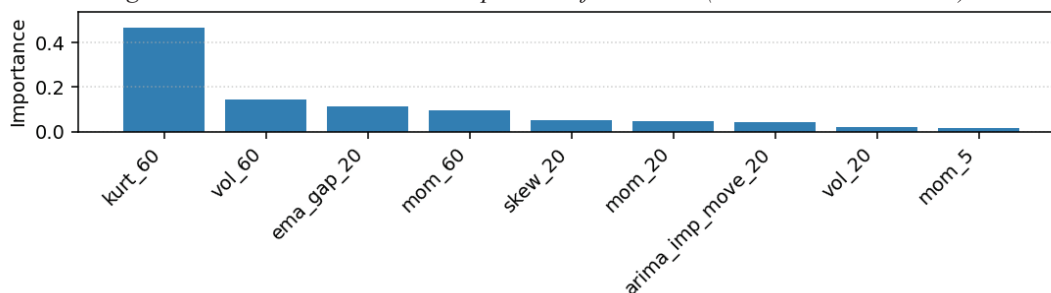
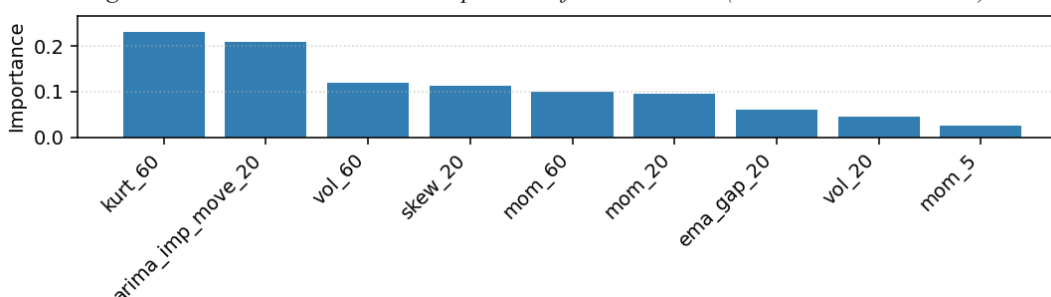


Fig 7.2. Random Forest Feature Importance for PetroChina(1-Month Ahead Return)

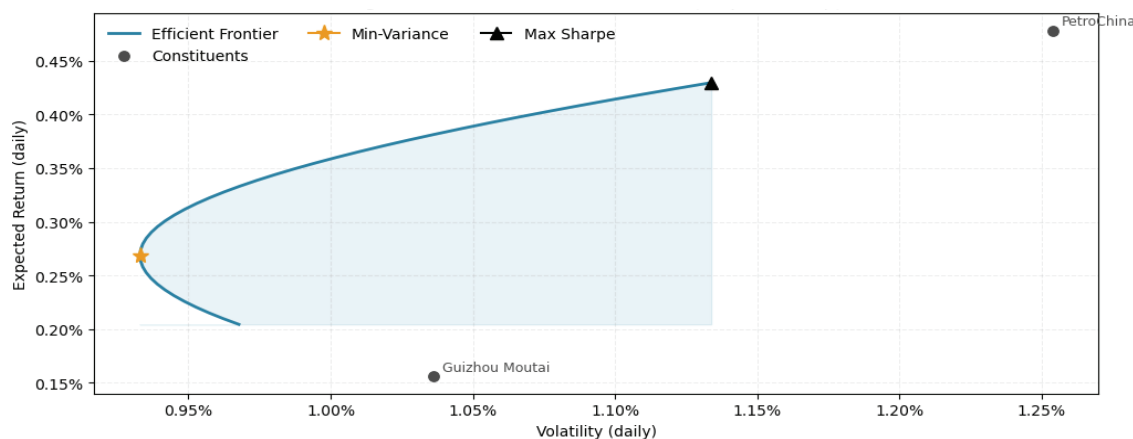


As shown in the figure, the Random Forest feature rankings for Guizhou Moutai and PetroChina reveal distinct drivers of one-month-ahead returns. For Moutai, sixty-day kurtosis (kurt\_60) overwhelmingly dominates, highlighting the central role of tail-risk in shaping predictive content, with longer-horizon volatility and momentum playing secondary roles and ARIMA-based measures contributing little. In contrast, PetroChina exhibits a more balanced structure: ARIMA-implied twenty-day moves (arima\_imp\_move\_20) and kurtosis both emerge as top predictors, supported by medium-horizon volatility and skewness. Across both firms, short-horizon signals such as five-day momentum and EMA gaps carry little weight, consistent with weak persistence at monthly horizons.

#### 5.4 Mean–variance opportunity set and allocation

Figure 8 displays a concave efficient frontier, indicating that the covariance estimate is numerically stable despite the limited sample. The GMV portfolio (★) lies near the leftmost point of the set and delivers the sample risk floor with weights of roughly 65% Kweichow Moutai and 35% PetroChina, reflecting the relative volatilities and correlation over the window. The maximum-Sharpe allocation (▲) tilts strongly toward PetroChina (≈85%), with Kweichow Moutai (≈15%) providing risk anchoring. Relative to either single constituent, the frontier confirms that non-naïve diversification achieves a material reduction in volatility for comparable (or higher) expected return. Geometrically, the optimizer selects the best risk–return trade-off given  $(\hat{\mu}, \hat{\Sigma})$ , while any subsequent overlay can scale exposure to respect tail-risk and volatility budgets.

Figure 8. Markowitz Efficient Frontier (RF-predicted mean)

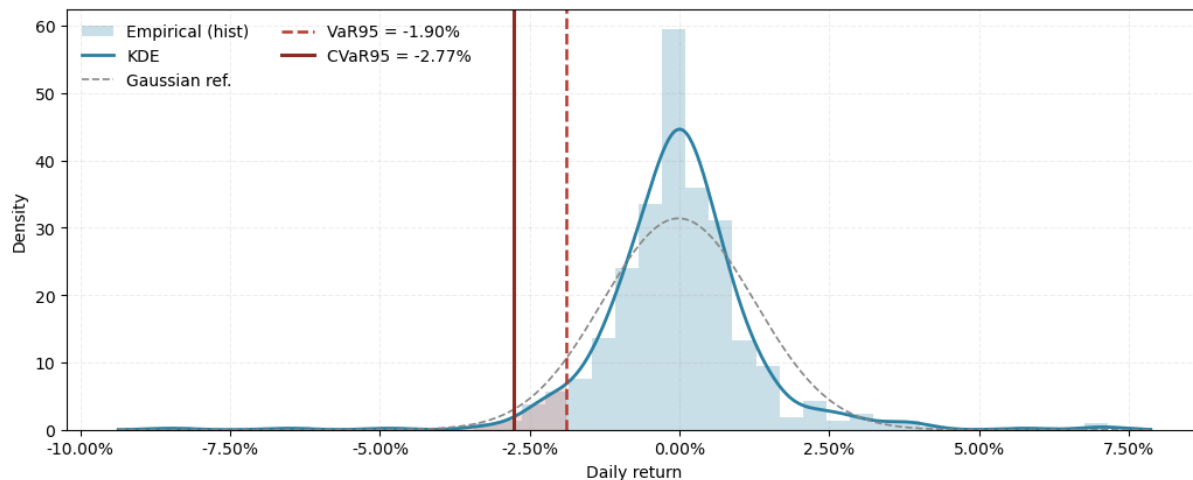


#### 5.5 Tail-risk profile and overlay behavior

As shown in Figure 9, the empirical distribution of the GMV portfolio's daily returns together with a Gaussian benchmark

matched on first and second moments. The left tail of the KDE exceeds the Gaussian reference, revealing negative skewness and excess kurtosis, which is a familiar stylized fact in equities. The historical  $VaR_{95}$  equals  $-1.90\%$ , while the  $CVaR_{95}$  is  $-2.77\%$ , confirming that expected losses conditional on a 5% exceedance are materially larger than the quantile loss itself. In our implementation these tail statistics serve as overlay controls: when a rolling, historically simulated VaR breaches the policy bound (e.g.,  $-3\%$  per day), portfolio exposure is scaled down ex-ante, and an additional volatility-targeting overlay rescales weights to a fixed risk budget. Consequently, the overlay converts signal strength into risk-aware allocations, tightening exposure precisely when forecast uncertainty and empirical tail risk are elevated.

Figure 9. Tail-Risk Profile(GMV, daily)



## 5.6 Performance and risk outcomes

Table 1. Portfolio Performance (two-year sample; monthly rebalancing; 10 bps one-way costs)

STRATEGY	%ANN.RETURN	%ANN.VOLATILITY	SHARPE	%MAX DRAWDOWN
PROPOSED	-4.53	10.72	-0.38	-15.69
EQUAL-WEIGHT	-4.93	20.90	-0.14	-27.26
BENCHMARK	-1.39	16.48	-0.00	-21.22

The proposed portfolio posted  $-4.5\%$  p.a. with  $10.7\%$  volatility (Sharpe  $-0.38$ ), improving on equal-weight in both return ( $-4.9\%$ ) and risk ( $20.9\%$ , Sharpe  $-0.14$ ), but trailing the index's smaller loss ( $-1.4\%$ ) at moderate volatility ( $16.5\%$ ). Maximum drawdown was  $-15.7\%$ , substantially shallower than both equal-weight ( $-27.3\%$ ) and the benchmark ( $-21.2\%$ ). Net: the strategy stabilized risk exposure relative to naïve diversification and the market, though it did not translate signals into positive absolute or excess returns during this sample.

Table 2. Historical Simulation Tail Risk at 95% (summary across rebalance windows)

%MEAN VaR95	%MEDIAN VaR95	%MEAN CVaR95	%MEDIAN CVaR95	BREACH RATE(WINDOWS)
-2.17	-2.19	-3.26	-3.37	5.56

Historical simulation indicates an average 95% VaR of about  $-2.2\%$  and CVaR of  $-3.3\%$ . The realized breach rate ( $5.6\%$ ) is close to the nominal 5% level, suggesting well-calibrated tail-risk estimates. This implies that the VaR overlays did not systematically understate or overstate risk, and the framework's tail control was consistent across rebalancing windows.

The return-capacity measure ( $\alpha_{ret} = 0.14$ ) indicated only modest forecasted gains, consistent with limited predictive ability. The VaR calibration factor ( $\kappa \approx 1.0$ ) and the volatility-targeting factor ( $\lambda \approx 0.99$ ) confirmed that realized risks were closely aligned with ex-ante forecasts, showing that the overlays functioned as intended. The model's implied mean daily return ( $\sim 0.0628\%$ , or  $\sim 15.8\%$  annualized) was positive, but trading costs and adverse realized conditions eroded this advantage. Together, these results suggest that the overlay machinery effectively stabilized risk exposure, though it did not generate positive Sharpe ratios in this sample.

## 5.7 Discussion

The extant research on Chinese A-shares has focused primarily on parametric VaR models, including GARCH-EVT, GARCH

with Student's t-errors, and score-driven NIG specifications<sup>[5, 8, 9]</sup>. These approaches have been shown to enhance tail fitting; however, they remain contingent upon distributional assumptions and are susceptible to misspecification in shifting regimes. The present study contributes to the existing literature by introducing a diagnostics-driven ARIMA process that explicitly identifies mean dynamics. This approach diverges from previous studies by ensuring that mean and volatility processes are identified separately and transparently, thereby providing a more robust foundation for risk modelling in emerging markets.

A secondary research trajectory has involved the integration of ARIMA with machine learning methodologies. Cai and Zhao applied ARIMA-Random Forest hybrids for price prediction, while Deng and Zheng et al. linked time-series forecasts with mean-variance portfolio optimisation. The preceding studies have not yet incorporated tail-risk measures. The present framework extends this line of research by applying Random Forest to ARIMA residuals, fusing features such as momentum, volatility, and higher moments to capture nonlinear risk interactions, which offers a theoretical breakthrough by linking time-series identification, feature learning, and risk quantiles into a coherent VaR framework<sup>[17, 18]</sup>.

The utilisation of portfolio-level applications of VaR remains constrained within the Chinese market. Zhang, for instance, employs GARCH-based VaR in sectoral portfolios but demonstrates that such models have a tendency to underestimate extreme losses due to distributional rigidity. The present study proposes a novel integration of the ARIMA-RF hybrid within a VaR-aware portfolio optimisation and backtesting framework. This approach directly links forecasting with allocation and risk budgeting, thereby transcending the limitations of the descriptive evaluation of tail-fit performance observed in earlier research.

From a practical perspective, this theoretical framework contributes to quantitative risk management and portfolio strategy in two distinct ways. Firstly, it provides a value-at-risk (VaR)-aware allocation mechanism that directly connects forecasts with portfolio decisions, thus moving beyond the scope of descriptive tail modelling<sup>[19]</sup>. Secondly, the incorporation of machine-learning feature fusion enables practitioners to account for multiple risk drivers, such as momentum, realised volatility and distributional shape, all within a single portfolio control system. This provides investors and risk managers in emerging markets with a more flexible and operational tool for managing downside exposure, supporting both capital allocation and risk budgeting in volatile environments.

The present study advances this literature by applying a diagnostics-driven ARIMA process that separates mean and volatility dynamics, followed by Random Forest applied to ARIMA residuals to capture nonlinear interactions among momentum, realized volatility, and higher moments. This integration allows VaR-aware portfolio optimization with overlays, stabilizing risk exposure relative to equal-weight and benchmark portfolios. Empirical results indicate that the proposed framework achieves well-calibrated VaR and ES estimates, with exceedance rates consistent with regulatory thresholds, and that overlay mechanisms such as volatility targeting and VaR-based scaling improve downside protection.

Nevertheless, limitations remain. The framework still relies on normality when translating conditional forecasts into VaR, which may understate extreme losses during crisis periods. Future research could adopt quantile-learning algorithms such as Quantile Random Forests<sup>[20]</sup>, quantile forests for time-series applications<sup>[21]</sup>, and MIDAS quantile Random Forests for mixed-frequency VaR prediction<sup>[22]</sup>. Deep learning extensions, including quantile LSTM<sup>[23]</sup> and recurrent neural networks for VaR and ES<sup>[24]</sup>, may further enhance robustness by capturing nonlinear dependencies in tail risk. Moreover, machine-learning signals for crash-risk prediction<sup>[25]</sup> provide promising avenues for integrating systemic risk considerations into hybrid portfolio control frameworks.

## 6. Conclusion

This paper demonstrates that a diagnostics-driven ARIMA-Random Forest hybrid can improve portfolio risk management in the Chinese A-share market. By explicitly disentangling mean dynamics from residual volatility and embedding nonlinear features into risk quantile estimation, the framework strengthens the robustness of VaR forecasts and enhances portfolio stability. Empirical results indicate that the proposed strategy reduces volatility and drawdowns relative to naïve benchmarks, while maintaining consistent VaR calibration across rebalancing windows.

## Funding

No

## Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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# A Taxonomy of Dark Patterns on Digital Lending Platforms: Evidence from a Survey of 15 Digital Financial Platform

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**Abstract:** With the growth of digital finance, platforms like JD Finance and ZhongAn Finance have become key public funding sources. However, they often embed “dark patterns”, manipulative interface designs that undermine user rights. Based on a study of 15 major financial platforms, this paper identifies 10 prevalent dark patterns, including “forced registration” “ambiguous annualized rates” and “difficult account cancellation”. Case studies reveal their manipulative logic by exploiting users’ bounded rationality and restricting information access. Findings indicate that over 80% of platforms employ at least three such patterns, which disproportionately harm vulnerable groups like the elderly and students. To address these issues, we propose a tripartite governance framework integrating governmental regulation, platform self-assessment, and user empowerment, offering actionable insights for regulating digital financial services.

**Keywords:** Digital Finance; Dark Patterns; Financial Consumer Protection; Lending Platforms; Interface Manipulation

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## 1.Introduction

In recent years, digital finance has rapidly expanded into various markets, largely driven by its “low entry barriers and high convenience”. China’s digital finance user base has reached 960 million, accounting for 68.6% of the total population. Key segments such as third-party payment, online lending, crowdfunding, online insurance, online funds, and online trusts have all shown rapid growth<sup>[1]</sup>, with platforms such as JD Finance, ZhongAn Finance, and 360 Jietiao each maintaining over 10 million monthly active users. By leveraging algorithmic recommendations and streamlined procedures, these platforms enable users to complete loan applications seamlessly from home. Yet this apparent “convenience” masks underlying risks—some platforms deliberately employ interface designs that guide users toward unintended decisions, a strategy known as deploying “dark patterns”.

Unlike dark patterns encountered in e-commerce—such as disguised cart additions—those embedded in financial platforms pose direct threats to users’ fund security and credit history. For instance, some platforms present annualized interest rates deceptively, describing them merely as “0.02 yuan daily”. Thereby obscuring high borrowing costs. Others require users to provide phone numbers before displaying loan terms, infringing on personal privacy. Still others hide account cancellation options deep within multi-layered menus, leaving users trapped in unwanted subscriptions. By 2025, complaints related to dark pattern manipulation already constituted a growing share of financial grievances handled by the China Consumers Association, even exceeding those related to traditional financial services in certain categories—underscoring the urgency of



addressing this issue.

Current academic literature primarily examines dark patterns within e-commerce and social media contexts <sup>[2,3]</sup>. However, financial dark patterns—characterized by their high technical complexity and potential for rapid risk contagion—have not yet been systematically studied. This paper fills that gap by identifying and classifying ten forms of dark patterns observed across fifteen financial platforms. It aims to serve a dual purpose: first, to equip regulators with a clear, actionable taxonomy to support targeted supervision; and second, to enhance user awareness of manipulative designs, thereby helping to prevent financial harm. In doing so, it also encourages platforms to adopt more user-centered designs, supporting healthier and more sustainable development in the digital finance industry.

## 2. Definition and Types of Dark Patterns in Digital Financial Platforms

### 2.1 Definition of Financial Platforms and Their Dark Patterns

Digital financial platforms are online intermediaries that utilize digital technologies to deliver services such as credit lending, wealth management, and payment processing <sup>[4]</sup>. Representative examples include JD Finance, ZhongAn Finance, and Ant Group. These platforms, characterized by their algorithm-driven operations, have become integral components of the contemporary financial landscape.

Drawing on the foundational work of Mathur et al. <sup>[5]</sup>, this study defines digital financial dark patterns as interface strategies embedded in the design of these platforms. These strategies manifest through visual layouts, information framing, or process flows. They exploit users' bounded rationality, including cognitive biases and information asymmetries, to guide or compel individuals toward financial decisions they would not otherwise make, such as undertaking excessive loans or agreeing to hidden costs. The existence of dark modes is not for consumers to gain more benefits, but for the benefit of digital financial platforms <sup>[6]</sup>.

Compared to dark patterns in other domains, those found in financial contexts exhibit two distinctive traits. First, they carry direct financial consequences, immediately threatening users' fund security. For instance, ambiguous presentations of annualized interest rates can mislead borrowers into paying more than necessary. Second, they exert a persistent coercive influence: once users are engaged, they often encounter long-term constraints. A typical example includes interfaces that bury account cancellation functions deep within complex menus, effectively trapping users in ongoing relationships and continuously exposing them to promotions for high-interest financial products.

### 2.2 Types and Case Studies of Dark Patterns in Digital Financial Platforms

Table 1 presents a taxonomy of ten prevalent dark patterns identified across digital lending platforms. Each category is described in terms of its underlying manipulative logic, the platforms on which it was observed, and illustrative examples. The analysis covers major lending services, including Xiaoman Finance, JD Finance, and Zhonglian Finance.

**Lengthy User Agreement Previews** This pattern leverages users' reliance on intuitive judgment by presenting excessively long and complex user agreements or privacy policies, thereby discouraging careful review. Platforms such as Du Xiaoman Finance, Zhonglian Finance, Kejie Finance, Kaka Hua, Xiaofu Loan, 58 Haojie, Ctrip Finance, and Ping An Finance adopt this approach. For example, Ping An Finance employs an extended privacy policy and a separate list of third-party data sharing arrangements, making it difficult for users to locate key clauses. Several other platforms present lengthy agreements immediately upon app launch, effectively prompting users to grant broad permissions without thorough reading.

**Concealing Key Information Before Verification** Under the guise of identity verification, platforms deliberately withhold essential information—such as interest rates, handling fees, and guarantee fees—until users complete facial recognition. As a result, borrowers cannot assess the true cost of loans in advance. This practice is widespread across platforms including Du Xiaoman Finance, JD Finance, Zhaolian Finance, Doudou Qian, Anyihua, Xiaoying Card Loan, Jixiang Hua, 360 Jietiao, Zhongyi Rong, Kejie Finance, Kaka Hua, Huoshan Rong, Xiaofu Loan, 58 Haojie, Ctrip Finance, Didi Finance, and Ping An Consumer Finance. In these cases, users only gain access to fee details after submitting to biometric verification.

**Compulsory Registration** Platforms condition service access on the provision of personal information—typically a mobile phone number—effectively barring unregistered users from any form of engagement. Nearly all surveyed platforms enforce this policy, including Du Xiaoman Finance, JD Finance, ZhongAn Finance, Doudou Money, Anyi Hua, Xiaoying Card Loan,

Jixiang Hua, 360 Jietiao, Zhongyi Rong, Kejie Finance, Kaka Hua, Huoshan Rong, Xiaofu Loan, 58 Haojie, Ctrip Finance, Didi Finance, and Ping An Consumer Finance. A typical example is the universal requirement to enter a mobile number and verification code before users can view their potential loan limits. Huoshan Finance imposes further restrictions by requiring users to provide two emergency contacts and specify their relationships before proceeding.

**Repeated Exit Prompts** When users attempt to leave the loan application interface, platforms deploy incentive-based or emotionally persuasive tactics to deter exit. This pattern is observed on JD Finance, Doudou Money, Xiaoying Card Loan, Jixiang Hua, Huoshan Rong, and Ping An Consumer Finance. For instance, when a user tries to exit the Doudou Money interface, a pop-up appears highlighting a pre-approved credit line of ¥20,000 and promising disbursement within three minutes—using urgency and high credit limits to persuade users to stay.

**Visual Manipulation for Click Induction** Platforms strategically deploy bold colors, enlarged typography, and dynamic animations to direct user attention toward loan-related functions. This technique is used by JD Finance, 360 Jietiao, Zhongyi Rong, Kejie Finance, Huoshan Rong, and Didi Finance. 360 Jietiao, for example, displays a prominent “New User Benefits” banner on its homepage, while Didi Finance promotes a “30-Day Interest-Free Voucher” with a visually striking “Exceptional Value” label to encourage engagement.

**Automatic Matching of Lending Institutions** This pattern removes user autonomy by automatically assigning a partner lending institution without offering a choice. Platforms such as Zhongchui Ronghe and Kejie Finance implement this approach. In some cases, even before users complete facial recognition—often after only entering an ID number—the system displays a “Lending institution matched” notification. Users subsequently receive unsolicited contact via SMS, phone calls, or WeChat from the assigned institution, with no option to select or switch providers.

**Concealing Key Contract Terms** Critical contractual clauses—such as those related to user data collection or liability disclaimers—are embedded within lengthy, complex agreements. Users must accept the entire document to proceed, with no option to object to specific terms. This practice is observed across Du Xiaoman Finance, JD Finance, Zhonglian Finance, Doudou Money, Anyihua, Xiaoying Card Loan, Jixiang Hua, 360 Jietiao, Zhongyi Rong, Kejie Finance, Kaka Hua, Huoshan Rong, Xiaofu Loan, 58 Haojie, Ctrip Finance, Didi Finance, and Ping An Consumer Finance. For instance, Du Xiaoman Finance buries clauses authorizing the collection and processing of user data by third-party entities such as Baidu and Megvii deep within its agreement, making them nearly impossible to identify without detailed scrutiny.

**Ambiguous APR Disclosure** Platforms use expressions such as “daily interest” or wide interest rate ranges to obscure the true cost of borrowing, leading users to underestimate repayment obligations. This occurs on Du Xiaoman Finance, Anyi Hua, Jixiang Hua, 360 Jietiao, Kejie Finance, Kaka Hua, 58 Haojie, Ctrip Finance, Didi Finance, and Ping An Consumer Finance. Ping An Consumer Finance, for example, states an “Annualised Interest Rate 4%–24%” alongside equivalent daily rates, but fails to specify the eligibility criteria for obtaining the lowest 4% rate.

**Persistent User Accounts** Even after users deactivate their accounts, platforms retain personal data and restore full account functionality upon re-login. Du Xiaoman Finance and JD Finance, among others, engage in this practice. For example, users who deactivate JD Finance or Du Xiaoman accounts and later log in again with the same mobile number will find their previous accounts fully restored—confirming that data were not permanently deleted.

**Obstruction of Account Cancellation** Platforms hide cancellation pathways and impose cumbersome procedures to raise barriers to exit. Affected platforms include Du Xiaoman Finance, JD Finance, ZhongAn Finance, Doudou Money, Anyi Hua, Xiaoying Card Loan, Jixiang Hua, 360 Jietiao, Kejie Finance, 58 Haojie, Ctrip Finance, Didi Finance, and Ping An Consumer Finance. In one instance, Doudou Qian requires a 15-day waiting period to finalize account closure. Many other platforms conceal cancellation options within the app interface, forcing users to navigate AI customer service systems to uncover the required procedure.

*Table 1: Taxonomy and Manifestations of Financial Dark Patterns*

Category	Manipulative Logic	Examples
Lengthy Agreement Previews	Exploits cognitive inertia by presenting complex texts to deter thorough review.	Ping An Finance uses extensive privacy policies; multiple platforms present agreements immediately upon app launch.

Category	Manipulative Logic	Examples
Pre-verification Information Concealment	Creates information asymmetry by withholding key terms until after identity verification.	Users across 15 platforms cannot view guarantee fees or final interest rates before completing facial recognition.
Compulsory Registration	Holds service access hostage to compel disclosure of personal information.	All platforms require registration to view loan limits; Hushan Finance further demands emergency contact details.
Repeated Exit Prompts	Employs financial incentives or urgency to reverse user exit decisions.	Doudou Money displays a pop-up offering a ¥200,000 credit limit when a user attempts to exit the loan page.
Visual Manipulation	Guides user attention and clicks to loan products through salient visual design.	360 Jietiao highlights “New User Benefits”; Didi Finance uses “Exceptional Value” tags for loan vouchers.
Automatic Lender Matching	Deprives users of choice by auto-assigning a lending partner without consent.	Zhongyirong and KeJie Finance trigger “lender matched” notifications after users merely input an ID number.
Hidden Contract Terms	Buries critical clauses on data collection and liability in lengthy, complex agreements.	Duxiaoman Finance conceals clauses about sharing user information with Baidu and Megvii within its contract.
Ambiguous APR Disclosure	Obscures true borrowing costs using “daily interest” or wide ranges, misleading users.	Ping An Consumer Finance states an APR of 4%–24% but omits the eligibility criteria for the lowest rate.
Persistent Accounts	Prevents a clean break by retaining user data and reactivating accounts upon re-login.	JD Finance and Duxiaoman Finance accounts remain active with original usernames after cancellation.
Obstructed Account Cancellation	Increases exit costs by hiding cancellation entries and imposing cumbersome procedures.	DoudouQian imposes a 15-day waiting period; others hide the option, requiring contact with AI customer service.

## 2.3 Manipulation Mechanisms of Dark Patterns

The ten dark patterns previously identified primarily function by exploiting users’ bounded rationality. Proposed by Simon, this theory contends that human decision-making is inherently limited by cognitive capacity and information access<sup>[7]</sup>. Digital financial platforms intensify these limitations through two principal methods.

First, they induce information asymmetry. Practices such as concealing key information prior to verification or embedding critical clauses within lengthy contracts serve to delay or obscure essential details regarding interest rates and fees. As a result, users are deprived of the information necessary for informed decision-making and become more reliant on platform guidance.

Second, they leverage cognitive biases. For instance, lengthy agreement previews exploit cognitive inertia, whereby users tend to accept terms without thorough review due to the mental effort involved. Similarly, ambiguous annualised interest rates capitalize on numerical perception bias, leading users to perceive a cost phrased as “0.03 yuan daily” as significantly less impactful than the equivalent “10.95% per annum”.

The interplay of these mechanisms leaves even reasonably cautious users vulnerable to manipulation. Addressing these practices is thus critical; failure to do so may not only perpetuate user harm but also precipitate a broader loss of trust in digital financial markets.

## 3. The Multidimensional impacts of Dark Patterns in Digital Financial Platforms

### 3.1 Harm to Financial Consumers

Dark patterns inflict direct and escalating harm on financial consumers, with a pronounced tendency to disproportionately affect vulnerable groups. The adverse impacts progress from tangible financial losses to profound rights violations<sup>[8]</sup>.

First, these designs lead to significant financial losses through hidden costs and misjudgment risks. Ambiguous annualized interest rates and undisclosed fees prior to verification are primary culprits. Most platforms display only broad APR ranges on their homepages or employ misleading promotions—such as “30 days interest-free” (JD Finance), “Exceptional Value” (Didi Finance), or “Borrow £1000 for 12 months, daily fee from 12 pence, APR from 7.2%” (360 Jietiao)—which create a false impression of low costs and prevent users from accurately assessing the true expense of loans.

Second, dark patterns facilitate privacy breaches through mandatory authorization and subsequent information misuse.

Practices like forced registration and contracts that conceal data-sharing clauses result in excessive collection of personal data. For instance, among the 15 lending platforms examined, many push advertisements claiming “You have a borrowing limit” immediately after obtaining users’ mobile numbers. In more severe cases, some platforms share user identification details with third-party marketing firms, leading to a surge in nuisance calls and further violation of personal privacy.

Finally, users often find their rights entrapped, primarily due to difficult account closure and persistent data retention. Mechanisms such as perpetual accounts and intentionally cumbersome cancellation procedures prevent users from cleanly exiting platform ecosystems. JD Finance, for example, continues to retain user accounts and push advertisements long after borrowing activities have ceased. Meanwhile, Doudouqian’s 15-day account closure review process can be invalidated by any accidental login during that period. These obstructive designs are particularly challenging for elderly users with lower digital literacy, who may struggle to locate closure options and thus remain perpetually subject to unwanted platform engagement.

### 3.2 Harm to Financial Markets

Dark patterns also inflict profound harm on financial markets, which manifests in two principal dimensions: the distortion of competitive order and the amplification of systemic risk.

On the one hand, they disrupt fair competition by encouraging monopolistic behavior among leading platforms and triggering a “race to the bottom” consistent with Gresham’s Law. Resource-rich platforms—such as JD Finance and 360 Jietiao—leverage dark patterns to monopolize user traffic. For example, JD Finance prioritizes its own lending products in recommendation lists, while requiring external banks to pay for visibility, effectively suppressing lower-interest alternatives. In response, smaller platforms are compelled to adopt similar manipulative tactics—such as forced registration and ambiguous interest rate disclosures—in order to remain competitive. This dynamic creates a vicious cycle in which platforms that refrain from deploying dark patterns lose market share, thereby reinforcing industry-wide degradation.

On the other hand, dark patterns heighten the transmission of systemic risk by increasing user defaults and platform bad debt levels. Through repeated prompts and visual manipulation, users are induced to borrow impulsively. However, when they later realize the true cost of loans—obscured initially by ambiguous interest rates—many struggle to repay, leading to a rise in defaults. An increase in non-performing borrowers directly elevates platforms’ bad debt ratios. If multiple institutions face such issues simultaneously, a liquidity crunch may ensue, potentially destabilizing the broader financial system.

### 3.3 Harm to Financial Institutions

Although dark patterns may temporarily improve key performance indicators for platforms, they ultimately undermine long-term sustainability by eroding user trust and satisfaction, which in turn leads to decreased user retention and borrowing activity in subsequent periods. A case in point is China UnionPay Finance, which was fined 2.9 million yuan in 2021 by the former China Banking and Insurance Regulatory Commission (CBIRC) for 19 regulatory violations, including the use of exaggerated and misleading marketing—a clear illustration of how such practices can inflict severe reputational damage.

Moreover, dark patterns inhibit meaningful financial innovation. By diverting resources toward the development of manipulative interface designs, platforms neglect the more socially valuable goal of creating accessible and transparent inclusive financial products. Examples include user-friendly wealth management tools tailored for rural populations or straightforward loan offerings for micro-enterprises. This misallocation of developmental focus fundamentally undermines the original policy intent of digital finance to promote broader financial inclusion.

## 4. Governance Recommendations for Dark Patterns in Digital Finance

Currently, countries worldwide have initiated regulatory and governance efforts targeting dark patterns across various sectors<sup>[9]</sup>. Addressing the dark patterns documented in this study requires a coordinated effort among regulators, platforms, and users. The following recommendations are structured to correspond directly to the issues identified in the preceding analysis.

### 4.1 Regulatory Authorities: Explicitly Prohibit Deceptive Practices

Regulators should establish and enforce a clear negative list that explicitly bans prevalent deceptive practices such as compulsory registration, hidden contractual terms, and unreasonably difficult account closure. For instance, platforms must be required to allow users to view loan products and interest rates prior to registration; the account cancellation process should be limited to no more than three steps, with any mandatory review period not exceeding one business day—thereby

addressing excessively long waiting periods such as the 15-day closure process of DouDouQian or the three-day delay at KeJie Finance. Platforms identified as employing multiple dark patterns should be prioritized for inspection, and substantial penalties should be imposed to create a meaningful deterrent against such manipulative behaviors.

## **4.2 Lending Platforms: Enhance Transparency and Simplify Processes**

Platforms referenced in this study should take targeted corrective actions corresponding to their specific dark pattern usage. Those displaying only annualised interest rate ranges on their homepages—such as Anyi Hua and 360 Jietiao—should be required to disclose the actual annualised interest rate applicable to the individual user, rather than presenting ambiguous ranges. Platforms with cumbersome account cancellation procedures, including JD Finance and DouDouQian, must introduce a clearly visible “Cancel Account” option within the homepage settings menu and eliminate protracted review periods. Furthermore, platforms that embed critical clauses within lengthy contracts—such as JD Finance and ZhongAn Finance—should summarise key information regarding data usage and fee structures in a single-page, easy-to-read format placed at the beginning of the agreement, sparing users the need to search through dense legal text.

## **4.3 Users: Strengthen Digital Literacy and Adopt Proactive Rights Protection**

End users also play a critical role in mitigating the risks associated with dark patterns. It is recommended that individuals actively improve their financial literacy by using official educational resources such as the People’s Bank of China’s Financial Consumer Protection Platform to better understand concepts such as annualised interest rate calculation, thereby reducing their susceptibility to misleading representations like “low daily interest rates.” In cases where platforms are found to employ hidden interest schemes or other deceptive practices, users should not hesitate to assert their rights through official reporting channels such as the 12315 Platform or the central bank’s complaint hotline. It is worth noting that by 2024, some users have already successfully obtained compensation for interest losses through legal action, demonstrating that proactive rights protection can yield tangible outcomes.

## **5. Conclusion**

Through an in-depth analysis of 15 digital finance platforms, we have identified and categorized ten distinct types of dark patterns prevalent in the online lending sector. We have elucidated their operational mechanisms, which systematically exploit users’ bounded rationality through information asymmetry and cognitive biases. The harms imposed by these deceptive designs are examined across three critical dimensions—financial consumers, market competition, and institutional integrity—revealing that such practices not only lead to direct financial harm and privacy infringement but also distort competitive fairness and constrain genuine financial innovation.

Although regulatory efforts targeting dark patterns have been initiated, we argue that current standards and supervisory capacity remain inadequate to fully address their evolving manifestations. The original ethos of digital finance—centered on inclusivity and accessibility—is fundamentally compromised by the proliferation of such manipulative designs. Moving forward, we emphasize the need for a collaborative governance framework that integrates rigorous government standard-setting, proactive self-rectification by platforms, and enhanced digital literacy among users. Such a multi-stakeholder approach is necessary to reorient the industry toward a more transparent and user-centric developmental path.

In further research, we intend to expand the scope and sample diversity of platform analysis, with particular attention to the disproportionate impact of dark patterns on vulnerable groups such as rural residents and micro-enterprise owners. We believe a more granular understanding of these differential effects will help in crafting targeted regulatory responses and fostering a more equitable digital financial ecosystem.

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No

## **Conflict of Interests**

The authors declare that there is no conflict of interest regarding the publication of this paper.

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# Research on the Configuration Path of Digital Transformation of Specialized, Sophisticated, Distinctive and Innovative Enterprises: An fsQCA Analysis Based on the TOE Framework

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**Abstract:** It is imperative for Specialized, Sophisticated, Distinctive and Innovative Enterprises to accelerate their digital transformation, as this is a fundamental requirement to break through technical “bottlenecks” and secure a leading competitive advantage. From the perspective of TOE theory framework, this paper adopts the fuzzy-set qualitative comparative analysis(fsQCA) method, selecting 27 listed Specialized and Innovative Enterprises in Guangzhou as the research sample to explore the configurationa adaptation paths of their digital transformation. It is found that there is no single antecedent factor that constitutes a necessary condition for the digital transformation of specialized and special enterprises, but there are three configuration paths that drive their high digital transformation, namely, “technology-led-policy support”, “market-led-scale empowerment”, and “multi-dimensional collaboration-environmental support”; However, the non-high digital transformation is restricted by two configuration paths: “double shortage of technology-weak policy support”, “weak organization-poor market adaptation”. Among them, R&D investment at the technical level and antecedent conditions of human capital at the organizational level are particularly important, which are the key supporting elements for the high digital transformation of specialized and innovative enterprises. This paper enriches the related research on digital transformation of specialized and innovative enterprises, and provides a reference for formulating the adaptation path of digital transformation of specialized and innovative enterprises.

**Keywords:** Specialized; Sophisticated; Distinctive and Innovative Enterprises; Digital Transformation; TOE Theoretical Framework; Configuration Research

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## 1.Introduction

The Central Economic Work Conference in 2024 clearly pointed out that it is necessary to “strengthen the guidance of scientific and technological innovation, accelerate the digital transformation of specialized and new enterprises, and break through the’ neck-stuck “technical bottleneck”. According to the data released by the Ministry of Industry and Information Technology, by the end of 2024, the number of specialized and innovative “Little Giant” enterprises in China had exceeded 12,000, of which over 85% were concentrated in the core fields of manufacturing. “Specialization and novelty” is a multi-dimensional and complex concept, which generally refers to those enterprises with a high technical level, strong innovation ability, and strong market competitiveness, and has the characteristics of specialization, refinement, and novelty. It is the

main force to solve the current “stuck neck” technical problems and promote independent innovation in the industrial chain and supply chain. Theory and practice show that digital transformation is the reconstruction of value creation mode driven by digital technology, which helps to reshape the value creation of specialized and special new enterprises, and is an inevitable choice for specialized and special new enterprises to break through key core technical barriers and enhance core competitiveness (Lei & Tan, 2021; Qi & Xiao, 2020). Most of the existing specialized and innovative enterprises are still in the primary stage of digital transformation, and their in-depth application is insufficient. The main reason is that compared with large enterprises, specialized and innovative enterprises have the characteristics of small scale and weak ability to obtain external resources, and their digital transformation also presents the prominent contradiction of “strong willingness to transform but weak ability” and “urgent demand but vague adaptation path” (Yu et al., 2023). Therefore, it is of great theoretical and practical value to guide specialized and innovative enterprises to accelerate digital transformation.

The existing research focuses on the digital transformation of specialized and innovative enterprises. Based on the resource-based view, some scholars believe that unique resources such as R&D investment, technical capability, and digital talent reserve, which are difficult to replace and replicate, are the core driving factors of digital transformation (Qi et al., 2023; Mao & Dun, 2023; Zhang et al., 2022). From the perspective of dynamic capability theory, some scholars pointed out that when enterprises cope with changes in internal and external innovation environment, the abilities of environmental perception, learning absorption, integration and reconstruction are the driving force for enterprises to cope with changes in internal and external innovation environment, integrate and utilize internal and external resources, and realize digital transformation (Cao et al., 2024; Ma et al., 2022); Another study emphasizes that policy support and market-oriented environment can provide strong external empowerment for digital transformation from the perspective of institutional theory (Zhou et al., 2025; Wang, 2024). The existing literature research on the digital transformation of specialized and innovative enterprises provides theoretical support for the development of this study, but the existing research has two limitations: First, it focuses on the “net effect” analysis of a single factor, ignoring the interaction of multi-dimensional factors of technology, organization and environment; Second, there is a lack of targeted discussion on regional heterogeneity and industry differences, which makes it difficult to form a replicable transformation path for regions and industries.

The TOE framework (technology-organization-environment) provides theoretical support for solving this dilemma. This framework integrates influencing factors from internal and external dimensions of enterprises, and is suitable for analyzing the transformation mechanism in complex situations. Therefore, starting from the TOE theoretical framework, this paper adopts the fuzzy set qualitative comparative analysis (fsQCA) method, takes 27 specialized and innovative listed enterprises in Guangzhou as research samples, and deconstructs the question: What are the core influencing factors of digital transformation of specialized and innovative enterprises? How do multiple factors drive digital transformation through the configuration effect? This paper reveals the nonlinear mechanism of “multiple causes and one effect” in digital transformation, in order to provide theoretical and practical reference for the differentiated transformation path of specialized and innovative enterprises.

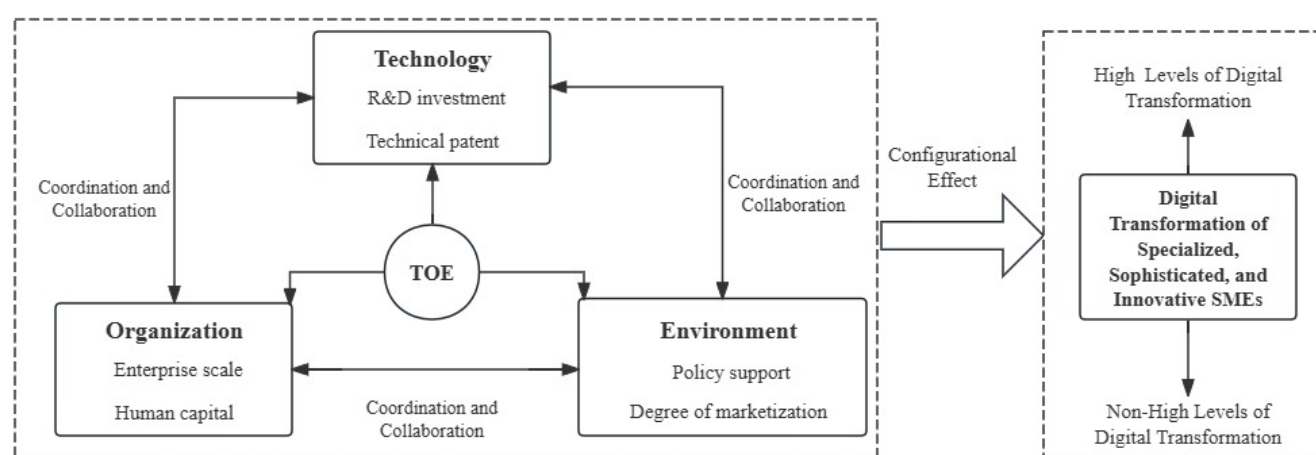
## 2. Theoretical framework

The TOE theoretical framework, based on technology-organization-environment, was put forward by researchers Tornatzky and Fleischer in 1990. It is mainly suitable for attribution analysis of enterprise or organization behavior decisions in different situations, and is essentially a comprehensive analysis framework based on technology application situations (Qiu, 2017). Combined with the characteristics of “small but specialized, small but refined” of specialized and innovative enterprises, the antecedent conditions are screened based on three levels of technology, organization, and environment, and the analysis framework of digital transformation of specialized and innovative enterprises is constructed from the perspective of configuration (as shown in Figure 1).

First, the technical level. The most typical feature of the technical level of specialized and innovative enterprises is “novelty”, that is, technological innovation, which directly determines the R&D and innovation potential of digital technology of enterprises. The essence of digital transformation is the deep integration of digital technology and business processes, which requires continuous R&D investment at the front end and sufficient technical patent reserves at the back end. (1) From

the front end, on the one hand, high R&D investment can accelerate the digital technology reserve of enterprises (such as industrial software development, digital platform construction, smart device upgrade, etc.) and provide technical support for the digital transformation of enterprises (Wu et al., 2021); On the other hand, R&D investment intensity reflects enterprises' acceptance of digital transformation, and enterprises with higher innovation investment can attract digital technical talents to join, forming a positive cycle of "investment-technology-talents" (Zhao et al., 2021). (2) From the back end, a technology patent is a scarce, exclusive, and economically valuable resource, which is the direct embodiment of the digital technology innovation ability of enterprises and the core asset of digital transformation. On the one hand, the more technology patents an enterprise has, the stronger its autonomy and controllability in the market, thus reducing its dependence on external technology supply (Qi et al., 2023); On the other hand, the accumulation of technology patents can enhance the bargaining power and market competitiveness of enterprises (Ano & Bent, 2022; Wang, 2024).

Figure 1 Theoretical Model



Second, the organizational level. The structural characteristics and resource base of an organization profoundly affect the digital transformation and development of enterprises (Mi, 2019). The organizational level is the internal guarantee for the digital transformation of specialized and innovative enterprises, which determines the absorptive capacity of enterprises to digital technology, the efficiency of resource integration, and the adaptability of management. Digital transformation is not only a technological change, but also a systematic reconstruction of enterprise organizational structure and management mode, which needs to be supported by appropriate organizational scale and sufficient human capital (Chirico & Nordqvist, 2010). (1) Enterprise scale reflects the resource reserve capacity and risk-taking level of specialized and innovative enterprises, and has a "double-edged sword" effect on digital transformation. On the one hand, a large enterprise scale can provide sufficient funds, equipment, and talent reserves for digital transformation (Wu et al., 2021); On the other hand, the organizational structure of large-scale enterprises is relatively complex, which may lead to inefficient transformation decision-making, increased transformation costs, and even hinder the digital transformation of enterprises. Although the smaller enterprise scale may limit the enterprise's resource acquisition and market share ability, for specialized and innovative enterprises, their "specialized and refined" characteristics make their business more focused and easier to play the role of scale advantage (Wu & Shi, 2022). (2) Human capital is the core subject of the digital transformation of specialized and innovative enterprises, which directly determines the efficiency and effectiveness of digital transformation. On the one hand, the high level of human capital can enable enterprises to learn efficiently, absorb digital technology knowledge and transform rapidly, thus accelerating the process of digital transformation of enterprises; On the other hand, the high level of human capital can accelerate the change of organizational culture, enhance the employees' sense of identity with digital transformation, and thus reduce the obstacles to digital transformation (Ano & Bent, 2022).

Third, the environmental level. Enterprise digital transformation is closely related to its dynamic environment, which determines the institutional environment, market demand, and resource acquisition of enterprise digital transformation. Because of its characteristics of "small but specialized, specialized and refined", the digital transformation of specialized

and innovative enterprises needs to be highly dependent on the support of the external environment (Jia et al., 2024). (1) Policy support is an important “catalyst” for the digital transformation of specialized and new enterprises, which can reduce the transformation cost and ease the financing constraints. The government adopts policies such as financial subsidies, tax incentives, and special support. On the one hand, digital transformation requires a large amount of capital resources. The government provides direct financial support or indirect incentives for digital transformation of enterprises through policy support such as financial subsidies, tax incentives and steering support, thus reducing the costs and risks of transformation (Boeing, 2016); On the other hand, policy support has a “signal effect”, which can attract financial institutions and other third parties to cooperate with enterprises, ease the financing constraints of enterprises, ease the financial difficulties of digital transformation, and form a collaborative empowerment of “policy-capital-technology” (Zhang et al., 2021). (2) The degree of marketization reflects the development level of market economy, the intensity of market competition, the circulation speed of products and elements, and the perfection of the system, which affects the decision-making of digital transformation of enterprises to a certain extent. First, a higher degree of marketization means that the market environment is more competitive, and it is easier for enterprises to promote digital transformation to gain market competitive advantage; Second, the improvement of marketization will enhance the liquidity of factor resources, attract digital talents, capital and other resources to gather, improve the efficiency of external resource allocation of enterprises, and provide sufficient resource support for the digital transformation of enterprises; Third, the high degree of marketization usually has a more perfect institutional environment, and the systems of intellectual property protection and data security supervision are more perfect, thus reducing the institutional risks faced by enterprises in digital transformation (Wang et al., 2023).

### 3. Research design

#### 3.1 Research Methodology

As a key strategic choice for the innovation and development of specialized and innovative enterprises, the realization process of digital transformation is not a linear result driven by a single factor, but a complex process influenced by multi-dimensional factors such as technical capability, organizational strategy, and external environment. Because traditional econometric research methods (such as regression analysis, structural equation model, etc.) only focus on analyzing the “net effect” of a single variable, it is difficult to reveal the “combination effect” formed by the interaction of multiple factors. Qualitative comparative analysis (QCA) is based on set theory, focusing on the combination of antecedent conditions, and paying attention to the complex causal relationship between antecedent condition configuration and result variables, which is more suitable for the research content and goal of this paper. Therefore, this paper chooses the past set qualitative comparative analysis (fsQCA) to explore how to dynamically match the configuration effect path of digital transformation of specialized and innovative enterprises from the perspective of TOE theory.

#### 3.2 Sample data

This paper strictly follows the principle of “representativeness, availability, and continuity” of data, and selects Guangzhou specialized and innovative listed enterprises as research samples. The sample screening process and standards are as follows: (1) Based on the list of specialized and special new enterprises published by Guangzhou Industry and Information Technology Bureau, combined with Wind database, “specialized and special new” listed enterprise label screening; (2) Excluding ST/\*ST enterprises and enterprises with data missing rate exceeding 20%; (3) Enterprises whose main business is traditional service industry (such as catering and retail) are excluded, so the digital transformation characteristics of such enterprises are atypical. Finally, 27 sample enterprises were determined, covering 162 observed values.

#### 3.3 Variable Definition and Calibration

##### 3.3.1 Result variables

Digital transformation (DT): Drawing lessons from the measurement methods of digital transformation such as Wu Fei et al. (2021) and Zhao Yuyu et al. (2021), the annual report data of 27 specialized and special listed companies in Guangzhou from 2019 to 2024 were obtained through Wind database and CSMAR database, and Python text mining technology was used to crawl the keywords such as “digital”, “intelligent”, “big data” and “cloud computing” in the annual report.

##### 3.3.2 Antecedent variables

R&D investment (RD): measured by the proportion of R&D expenditure to operating income;

Number of patents (PA): Measured by the sum of the number of technical inventions, utility model patents, and design patents owned by enterprises;

Enterprise Scale (SC): Measured by the total assets of the enterprise;

Human Capital (HC): Measured by the proportion of technical personnel in the total number of employees;

Policy support (PO): Measured by whether the enterprise has won national, provincial, municipal, district, and county awards or financial support, the value of “Yes” is 1, and the value of “No” is 0.

Marketization degree (MA): The marketization degree of the region where the enterprise is located is measured by using the marketization index of China’s provinces compiled by Wang et al. (2023), and the data is calculated by using the marketization index value of Guangdong Province in the corresponding year.

Combined with the measurement methods of the above result variables and antecedent variables, as well as the data collation of sample enterprises, the definitions of each variable and descriptive statistical analysis results are shown in Table 1.

*Table 1 Definition and descriptive statistical analysis of variables*

Variable type	Variable name	symbol	Measurement standard	Descriptive statistics				
				N	Mean	Sd	Max	Min
Result variable	Digital transformation	DT	The key dictionary is constructed by text mining method, and the index is calculated by entropy method	162	3.412	1.287	6.925	0.987
	R&D investment	RD	R&D expenditure/operating income (%)	162	7.563	2.587	12.876	1.987
	Technical patent	PT	Total number of technical inventions, utility models or software works and other proprietary technologies (pieces)	162	4.621	2.015	9.987	1.324
	Enterprise scale	SC	Total assets at the end of the year (10,000 yuan)	162	23.015	1.567	26.892	20.345
Antecedent variable	Human capital	HC	Number of technicians/total employees	162	23.876	9.567	48.234	5.987
	Policy support	PO	Whether it has won national, provincial, district and county awards or financial support; Obtained = 1, not obtained=0	162	0.667	0.472	1	0
	Degree of marketization	MA	Drawing lessons from the marketization index of China’s provinces compiled by Wang et al.(2023) and others to measure the degree of marketization in the region where enterprises are located	162	12.015	0.623	13.124	10.987

### 3.Variable calibration

According to the data and conditions of the result variable and the antecedent variable, the direct calibration method is used to assign all the variable data to the membership score of the fuzzy set. Among them, the anchor points (critical values) used for digital transformation, R&D investment, technology patents, enterprise scale, human capital and market environment calibration are set to 75% quantile (full membership, membership = 1), 50% quantile (intersection, membership  $\approx 0.5$ ) and 25% quantile (completely non-membership, membership = 0) For the policy support variable (PO), assign “1” directly to the supported samples, and set “0” to the unsupported samples. In order to avoid the situation where the membership degree is just 0.5, this paper adopts the method of adding 0.001 to the observation samples whose membership degree is less than 1. After calibrating according to the above method, the membership degree of all variables meets the requirements of a fuzzy set (the value range is 0-1), and the specific calibration results of anchor points are shown in Table 2.



Table 2 Variable calibration results

Variable name	symbol	Complete subordina- tion (75% quantile)	Crossing point (50% quantile)	Completely non-subordi- nate (25% quantile)	Calibration basis
Digital transformation	DT	4.325	3.385	2.215	Sample quantile
R&D investment	RD	9.234	7.452	5.312	Sample quantile
Technical patent	PT	6.123	4.563	2.987	Sample quantile
Enterprise scale	SC	24.567	22.987	21.654	Sample quantile
Human capital	HC	31.234	22.654	14.892	Sample quantile
Policy support	PO	1	0.5	0	Direct calibration of dummy variables
Degree of marketization	MA	12.789	12.003	11.456	Sample quantile

## 4. Empirical analysis

### 4.1 Necessity analysis of a single conditional variable

In the QCA method, if a single condition that causes the result to occur always exists, it is called a necessary condition of the result. Necessity analysis aims to test whether a certain antecedent variable constitutes a necessary prerequisite for the result variable (high digital transformation or non-high digital transformation), which is usually measured by whether the Consistency level is greater than 0.9. If the consistency threshold of the condition variable is greater than 0.9, it means that the necessary condition exists. In this paper, the fsQCA3.0 software is used to analyze the necessary conditions for the digital transformation of Guangzhou 27 “specialized and innovative” listed enterprises. The results show that (as shown in Table 3): the necessity consistency level of all antecedents is lower than 0.9, which indicates that no single antecedent condition in this paper constitutes a necessary condition for digital transformation, thus verifying that digital transformation needs multi-condition coordination rather than “complex configuration characteristics” driven by a single antecedent condition.

Through the results in Table 3, it can be found that the consistency of R&D investment is the highest (0.803), followed by human capital (0.786) and policy support (0.754), indicating that enterprises with high R&D investment, high human capital and policy support are easier to achieve high digital transformation; The consistency of technology patent (0.712) and marketization degree (0.698) is the second, and the consistency of enterprise scale (0.635) is the lowest. From the necessity of non-high digital transformation, ~ R&D investment (0.785) and ~ human capital (0.762) have the highest consistency, indicating that enterprises lacking R&D investment or human capital are more likely to fall into non-high transformation, and they are the “key bottlenecks” of transformation; The consistency of ~ policy support (0.731) and ~ technology patent (0.705) is second, which further verifies the core role of technology and policy.

Table 3 Necessity analysis results of a single condition

Antecedent condition	High digital transformation		Non-high digital transformation	
	Consistency	Coverage	Consistency	Coverage
R&D investment (RD)	0.803	0.832	0.235	0.256
~ R&D investment	0.246	0.268	0.785	0.807
Technical Patent (PT)	0.712	0.735	0.321	0.343
~ Technical patent	0.334	0.356	0.705	0.728
Enterprise size (SC)	0.635	0.658	0.402	0.425
~ Enterprise size	0.415	0.438	0.632	0.655
Human Capital (HC)	0.786	0.809	0.254	0.277
~ Human capital	0.267	0.29	0.762	0.785
Policy Support (PO)	0.754	0.777	0.289	0.312
~ Policy support	0.302	0.325	0.731	0.754
Marketization degree (MA)	0.698	0.721	0.335	0.358
~ Degree of marketization	0.348	0.371	0.678	0.7



## 4.2 Sufficiency Analysis of Conditional Configuration

In order to effectively identify the effective conditional configurations that lead to “high digital transition” or “non-high digital transition”, this paper draws lessons from Rihoux and Ragin’s research, and sets the consistency threshold to 0.8 (to ensure configuration reliability), PRI consistency to 0.8 (to avoid false configuration), and acceptable case frequency to 3 (considering the number and scale of samples). Simple solution, intermediate solution, and complex solution will be produced in the analysis process, and the combination of conditions of complex solutions may lead to too many solutions and the risk of over-fitting, thus reducing the external validity of the research results. Therefore, this paper follows the principle of “intermediate solution as the mainstay, simple solution as the supplement”, identifies the core conditions and marginal conditions of digital transformation of Guangzhou specialized and new enterprises, and obtains the final path.

### 4.2.1 Analysis of high digital transformation results

It can be seen from Table 4 that there are three configurations for Guangzhou specialized and special listed enterprises to realize high digital transformation, and the consistency levels of high digital transformation configurations are 0.935, 0.918 and 0.896 respectively, and the overall consistency of the three configurations is 0.912, which is greater than the consistency threshold of 0.8, indicating that all three configurations are sufficient conditions for specialized and special listed enterprises to realize high digital transformation. In addition, the coverage of the three configurations are 0.258, 0.243 and 0.231 respectively, indicating that the three configurations can explain 25.8%, 24.3% and 23.1% of the high digital transformation of specialized and special enterprises respectively; At the same time, the coverage of the solutions of the three configurations is 0.732, which indicates that the conditional configuration has a good explanatory power for the cases of specialized and new listed enterprises. According to the different core and edge conditions, this paper further summarizes the three high-digital transformation configurations into three paths:

#### 1. Technology-led-policy-supported driving path

In Configuration 1, two antecedent conditions (R&D investment and technology patent) exist at the core, which shows that high R&D investment and more technology patents play a core role; Policy support exists as marginal conditions, and the degree of marketization at the environmental level and the scale and quality of human capital at the organizational level can be flexibly adjusted, which highlights the important influence of technology leadership and policy support on the digital transformation of specialized and innovative enterprises. Configuration 1 path has the highest consistency, which is mainly suitable for technology-intensive enterprises (such as electronics and semiconductors, high-end equipment manufacturing, etc.). The core logic formed by the configuration 1 path is to accelerate the accumulation of digital technology reserves for technology investment, and policy support significantly reduces the cost of trial and error in transformation. A typical case of this kind of path is Ruike Laser. By developing the “Digital Production System of Fiber Laser”, the production efficiency is improved and the digital transformation is promoted.

#### 2. Market Leading-Driving Path of Scale Empowerment

In Configuration 2, the core conditions of organization level (enterprise scale, human capital) and marketization degree exist, which shows that large enterprise scale, more human capital, and high marketization degree play a core role; the Technical level (R&D investment and technology patent) and policy support conditions may be missing. This kind of path is generally suitable for enterprises with large scale and sufficient human capital (such as electronic information and intelligent manufacturing). The core logic of its formation is that the advantages of large enterprise scale can provide basic resources for enterprises to transform, more human capital can provide a guarantee for enterprises’ technology application ability, and a high degree of marketization can create a demand factor environment for enterprises. A typical case of this kind of path is Vision Electronics. Relying on Guangzhou’s high market environment, it has built a “digital R&D platform for intelligent interactive equipment”, integrating upstream and downstream supplier data and shortening the R&D cycle.

#### 3. Driving Path of Multi-dimensional Collaboration-Environment Support

In Configuration 3, the core conditions of environmental level (policy support and marketization degree) exist, which shows that good policy support and high marketization degree play a central role; R&D investment and enterprise scale exist as marginal conditions, and technology patents and human capital can be flexibly adjusted, which shows the multi-dimensional

synergy among technology, organization, and environment. This kind of path is generally suitable for enterprises with medium resources but a superior external environment (such as biomedicine and intelligent equipment). The logic of its formation provides internal support for enterprises for technology research and development and manpower scale, while policy support and market environment create external double thrust for enterprises. A typical case of this kind of path is Tongda Electric, which drives the digital transformation of the bus electrical system through “policy subsidy + market demand” and reduces the equipment failure rate.

*Table 4 Sufficiency analysis results of condition configuration for digital transformation of “specialized and innovative” listed enterprises*

Variable name	High digital transformation			Non-high digital transformation	
	Configuration 1	Configuration 2	Configuration 3	Configuration 4	Configuration 5
R&D investment (RD)	●	-	○	U	-
Technical Patent (PT)	●	-	-	U	-
Enterprise size (SC)	-	●	○	-	U
Human Capital (HC)	-	●	-	-	U
Policy Support (PO)	○	-	●	※	-
Marketization degree (MA)	-	●	●	-	※
Consistency	0.935	0.918	0.896	0.928	0.905
PRI consistency	0.889	0.867	0.853	0.876	0.862
Coverage	0.258	0.243	0.231	0.352	0.393
Unique coverage	0.097	0.085	0.082	0.123	0.138
Inter-group consistency adjustment distance	0.145	0.148	0.132	0.112	0.105
Overall PRI		0.868		0.869	
Consistency of global solutions		0.912		0.921	
Coverage degree of global solution		0.732		0.745	

Note: “●” indicates the existence of core conditions, and “U” indicates the absence of core conditions; “○” indicates the existence of edge conditions, and “※” indicates the absence of edge conditions; “-” indicates that the condition variable may exist or be missing; “Empty” means that the condition is unconstrained.

#### 4.3.2 Configuration analysis of non-high digital transformation

The adequacy analysis of non-high digital transformation aims to identify the combination of core conditions that hinder the realization of digital transformation. Table 4 shows that there are two configurations of non-high digital transformation; the consistency levels of the two configurations are 0.928 and 0.905, respectively, and the overall consistency of the two configurations is 0.869, which is greater than the consistency threshold of 0.8. At the same time, the overall solution coverage of the two configurations is 0.745, which means that these two configurations have strong explanatory power and relatively high reliability. It is worth noting that in Configuration 4 of non-high digital transformation, R&D investment and technology patent core are missing, and policy support is marginally missing, which shows that technical and policy support are the basic threshold for realizing high digital transformation in the antecedent conditions of digital transformation of specialized and special family enterprises. If they are missing at the same time, the digital transformation will directly fall

into a stagnation state; In Configuration 5, small enterprise scale, small human capital and low degree of marketization are another configuration path that hinders the realization of high digital transformation, mainly because the scale ability of the organization and a good market environment are the guarantee conditions for the realization of high digital transformation, and if they are weak at the same time, they will lead to the “powerlessness” of digital transformation.

## 5. Conclusion and enlightenment

### 5.1 Research conclusions

Based on the TOE theoretical framework, this paper deconstructs multiple concurrent factors and configuration paths affecting the digital transformation of specialized and innovative enterprises by the fsQCA method, taking 27 specialized and innovative listed enterprises in Guangzhou as research samples. The main conclusions are as follows:

- (1) There are three ways to drive the high-digital transformation of specialized and innovative enterprises, namely, “technology-led-policy support”, “market-led-scale empowerment”, and “multi-dimensional collaboration-environment support”, which are respectively adapted to specialized and innovative enterprises with technology-intensive, scale human capital, and environment adaptation, reflecting the digital high-digital transformation characteristics of “all roads lead to the same goal”.
- (2) Non-high digital transformation is mainly divided into two configuration paths: “double shortage of technology-weak policy support” and “weak organization-poor market adaptation”. The former reflects the “lack of basic threshold” of technology and policy, while the latter reflects the “insufficient implementation guarantee” of organization and market.
- (3) The factor of digital transformation of specialized and innovative enterprises is the result of multi-factor conditions. No single condition can realize the high digital transformation of specialized and innovative enterprises. The R&D investment at the technical level and the antecedent conditions of human capital quality at the organizational level are particularly important. If they are lacking or weak, the enterprises will easily fall into the bottleneck of transformation.
- (4) The digital transformation configuration path of specialized and innovative enterprises reflects the heterogeneity of industries, and different industry characteristics realize the digital transformation configuration path. For example, the electronic information industry prefers the path of “market leading-scale empowerment”, the high-end equipment manufacturing industry relies on the path of “technology leading-policy support”, and the biomedical industry needs “multi-dimensional collaboration-environmental support”.

### 5.2 Research Enlightenment

#### 1. Theoretical contribution

- (1) Combining with the characteristics of “small but specialized, small but refined” of specialized and innovative enterprises, the measurement of TOE dimensions is refined, and the “asymmetric configuration effect” is identified, enriching the application of the TOE framework in the digital field of specialized and innovative enterprises. (2) The fsQCA method captures the nonlinear relationship of “multiple causes and multiple effects” and “one cause and multiple effects”, identifies three equivalent paths and two obstacle configurations, makes up for the limitation of “linear hypothesis” in traditional regression analysis, and provides a new perspective for the study of causal mechanisms of digital transformation.

#### 2. Practical enlightenment

- (1) At the enterprise level, all kinds of enterprises should establish the concept of digital transformation and innovation, combine the unique and precise positioning of the industry, and avoid the shortcomings of factors. For example, technology-intensive enterprises (such as Ruike Laser and Gaoyun Semiconductor) should focus on the path of “technology-led-policy support”, increase investment in research and development, strengthen patent layout, and actively declare digital special policies to reduce transformation costs; Large-scale human capital enterprises (such as Vision Electronics and Yuncong Technology) should rely on the path of “market-led-scale empowerment”, integrate upstream and downstream digital resources through scale advantages, increase the proportion of R&D technicians, and use Guangzhou’s high market-oriented environment to meet customer needs and accelerate digital landing; Medium-sized enterprises with resources (such as Tongda Electric and Anbiping): adopt the path of “multi-dimensional collaboration-environmental adaptation”, rely on Guangdong-Hong Kong-Macao Greater Bay Area digital factor market to strive for policy support, and at the same time maintain basic

R&D investment and moderate scale expansion to make up for the shortcomings of single factor. (2) At the government level, the government should improve the differentiated and targeted policy supply support system and implement classified policies. For example, for the electronic information industry, financial subsidies for “digital scale subsidies” can be introduced; For the high-end equipment manufacturing industry, set up tax incentives for “special technology research and development”; For the biomedical industry, provide financial support of “multi-dimensional collaborative support”. (3) At the regional level, with the help of Guangdong-Hong Kong-Macao Greater Bay Area’s policy advantage of “digital factor market integration”, Guangzhou sample enterprises will be promoted to cooperate with digital technology enterprises in Shenzhen and Dongguan (such as Huawei and DJ), share industrial Internet platforms and digital talent resources, build a “digital transformation benchmark” enterprise, sum up replicable experiences and promote them among specialized and new enterprises in the city, and form a transformation pattern of “benchmark-overall improvement”.

### 3. Research deficiency and prospect

There are still the following shortcomings in this study: (1) The sample only covers 27 specialized and special newly listed enterprises in Guangzhou, and does not include unlisted specialized and special new enterprises. In the future, it can be expanded to specialized and special new enterprises in Guangdong-Hong Kong-Macao Greater Bay Area to enhance the universality of conclusions; (2) The antecedent conditions do not include organizational governance variables such as “ownership structure” and “intergenerational inheritance”, which can be introduced in the future to enrich the condition system; (3) Without in-depth analysis of the dynamic evolution of the path (such as path changes in different years), the time series fsQCA method can be used to explore the temporal heterogeneity of the transition path in the future.

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## Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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# Analysis and Implications of the Impact of the Sex Industry and Anime Industry on Japan's Foreign Trade

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**Abstract:** Against the backdrop of intensifying globalisation and competition in cultural soft power, the impact of specific industries on a nation's foreign trade has become increasingly complex and multifaceted. Japan, as the world's third-largest economy, features two seemingly disparate yet equally compelling industries within its foreign trade structure—the sex industry and the anime industry—both playing indispensable roles. This paper aims to systematically analyse the direct and indirect impacts of these two industries on Japan's foreign trade. The anime industry, as a core pillar of Japan's cultural exports, generates substantial trade surpluses through copyright licensing, merchandise, tourism, and other avenues, significantly enhancing the nation's image<sup>[1]</sup>. Meanwhile, the sex industry, operating within a legal grey area, though difficult to quantify precisely in terms of direct exports, makes a significant implicit contribution to the trade balance. This is achieved by fostering related content industries such as adult videos and adult games, as well as attracting specific types of inbound tourism. This paper will delve into the economic logic, operational models, and socio-cultural controversies surrounding these two industries. Building upon this analysis, it will explore implications for other nations—particularly China—in developing cultural industries while balancing societal values with economic benefits.

**Keywords:** Japan's Foreign Trade; Services Trade; Anime Industry; Sex Industry; Cultural Soft Power; Content Industries; Economic Impact

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## Introduction

Japan's economic miracle and achievements in foreign trade have long been recognised globally for its high-end manufacturing sectors such as automobiles, electronics, and precision machinery. However, entering the 21st century, with the restructuring of global value chains and the rise of the “experience economy”, industries centred on culture, creativity, and services have seen their share in international trade steadily increase. Within this transformative process, two distinctive Japanese industries—the anime industry and the sex industry—have emerged as variables of significant research value within Japan's foreign trade landscape, owing to their unique cultural permeability and economic driving force.

The anime industry, as the core of the ‘Cool Japan’ strategy<sup>1</sup>, has long transcended the realm of mere entertainment products to become a global calling card for Japanese cultural identity. Through diverse forms such as manga, animation, films, games, and merchandise, it has established an extensive global industrial chain. This not only generates substantial direct trade revenue but also indirectly boosts exports in sectors like tourism, food, and fashion by enhancing the nation's brand image. Its



success model is regarded as exemplary in converting cultural soft power into economic hard power.

In stark contrast lies Japan's sex industry. While nominally prohibited under the Anti-Prostitution Law, numerous loopholes in this legislation have fostered an extensive and intricate 'adult entertainment' sector. Operating long within a legal and moral grey area, this industry engages in virtually no direct international trade. Yet it is precisely this 'underground' status that has fostered a remarkable synergy with the content industry. The 'sexual content industry,' epitomised by the adult video sector, has not only cultivated a substantial domestic market but also 'exported' globally through various channels, becoming a discreet yet highly profitable component of Japan's content trade. Concurrently, its distinctive sexual cultural landscape attracts significant numbers of purpose-driven inbound tourists, exerting a notable influence on the service trade<sup>[1]</sup>.

Thus, analysing these two industries side-by-side is not sensationalism, but rather an effort to reveal the complexity and multifaceted nature of modern foreign trade. Traditional trade theory often focuses on tangible goods and standardised services, whereas these two industries exemplify precisely how intangible cultural values, social concepts, and emotional experiences can cross borders and translate into tangible economic benefits. This paper will first outline the current status and global influence of both industries. It will then conduct an in-depth analysis of their combined impact on Japan's foreign trade across three dimensions: direct trade contributions, indirect multiplier effects, and national image shaping. The analysis will explore the underlying challenges and controversies, ultimately distilling valuable insights for China and other relevant nations.

## **1.Global Influence and Economic Standing of Two Major Industries**

### **1.1 The Animation Industry: From Subculture to Global Mainstream – The Engine of 'Cool Japan'**

Japan's anime industry constitutes a highly mature and meticulously specialised industrial ecosystem. Its upstream sector comprises original works (manga, light novels), the midstream involves animation production (TV series, theatrical films, OVA), while the downstream encompasses comprehensive commercial development including copyright licensing, audiovisual products, games, merchandise, theme parks, and stage productions.

**Global Market Penetration:** Japanese anime has achieved profound global market penetration. From North America and Europe to Southeast Asia, its fanbase spans all age groups. Massive acquisitions by global streaming platforms like Netflix and Crunchyroll have further accelerated its globalisation. According to the Japan Animation Association, the Japanese animation industry reached a market size of ¥2.9 trillion in 2022, with overseas markets accounting for over 47% for the first time – ¥1.4 trillion – demonstrating its high dependence on external markets and formidable foreign exchange earnings capacity<sup>[3]</sup>.

**Cultural Symbol Export:** Works like Dragon Ball, Naruto, and One Piece have become shared memories for generations worldwide. Terms originating from ACG (animation, comics, games) culture, such as 'moe' and 'chuunibyou,' have even been incorporated into dictionaries across multiple countries. This export of cultural symbols imbues Japanese products with unique cultural value, granting 'Made in Japan' an emotional resonance among consumers that transcends mere functionality.

**The "Content is King" Business Model:** The anime industry's core lies in the creation and operation of IP (intellectual property). A successful IP can endure for decades, generating a long-tail effect through continuous content updates and commercial spin-offs. This content-centric model, driving cross-industry synergies, is key to maintaining competitiveness in international trade.

### **1.2 The Sex Industry: A Grey-Area Economic Giant and the Content Industry's 'Invisible Hand'**

Japan's sex industry, known as the 'fūzoku' sector, operates within a legally ambiguous yet astonishingly vast market. Estimates from various research institutions place its scale at several trillion to ten trillion yen, rivalling the anime industry. Its complexity lies in being not a single entity but a conglomerate of diverse business models deeply intertwined with other sectors.

**Legal Existence Within the Framework:** The Anti-Prostitution Law prohibits the act of 'sexual intercourse' but does not ban derivative services operating under guises such as 'companionship,' 'massage,' or 'socialising.' This has spawned numerous 'grey-area' businesses like 'bubble bath parlours,' 'fashion health salons,' and 'outcall services,' forming a vast underground economic system.

**Globalisation of the Adult Content Industry:** Unlike physical adult entertainment establishments, the sexual content

industry—represented by adult videos and games—possesses distinct export attributes. Japan's AV industry enjoys worldwide renown, with its productions distributed globally through both legal and illicit channels, particularly dominating Asian markets. Though lacking official statistics, the foreign exchange generated from overseas copyright sales and streaming revenue shares is substantial. Similarly, Japanese adult games like 'bishoujo games' maintain a dedicated overseas player base<sup>[4]</sup>.

The tourism sector's unique appeal: Japan's distinctive sexual culture—such as the red-light district culture of Kabukichō's Ichiban-gai and maid cafés—has evolved into a singular 'tourism resource,' drawing substantial numbers of overseas visitors seeking 'experiential consumption.' This form of experiential spending is directly recorded within Japan's service trade exports. Though difficult to quantify, its contribution to inbound tourism expenditure is evident.

## **2. Analysis of the Impact of Two Major Industries on Japan's Foreign Trade**

An 'invisible' source of surplus within Japan's services trade and intellectual property trade. Furthermore, inbound tourism expenditure constitutes another significant contributor. Visitors specifically drawn to experience Japan's nightlife or subcultures generate direct increases in Japan's services trade export revenues through their spending on accommodation, dining, and entertainment.

### **2.1 Indirect Stimulation Effects: Building a Culture-Centred Industrial Ecosystem**

The influence of these two industries extends far beyond their own spheres, stemming from their potent industrial linkage effects.

The Multiplier Effect of the Anime Industry:

Boosting Manufacturing Exports: Anime intellectual property (IP) drives substantial exports of manufactured goods. For instance, Gundam models stimulate demand for precision plastic moulds and toy manufacturing; clothing, luggage, and co-branded electronics under Pokémon IP licensing leverage its cultural influence to enhance export competitiveness.

Boosting Tourism Development: 'Anime pilgrimage tours' have become a hallmark of Japanese tourism. Towns hosting filming locations attract vast numbers of fans by establishing themed shops and hosting events.

### **2.2 Direct Trade Contributions: From Surplus Pillars to Implicit Foreign Exchange**

The anime industry's visible trade surplus: The direct trade contributions of the anime industry are readily apparent. Foremost are copyright and content licensing revenues, representing the core intellectual property trade. Foreign television networks and streaming platforms purchasing broadcast rights, overseas publishers acquiring manga publication rights, and gaming companies securing IP adaptation rights collectively generate substantial foreign exchange income for Japan. Secondly, tangible goods exports encompass Blu-ray/DVD discs, manga volumes, figurines, apparel, stationery, and other merchandise. These 'Made in Japan' cultural products command strong pricing power in international markets due to their high value-added nature and cultural resonance, constituting a significant surplus source within Japan's goods trade.

Implicit Foreign Exchange from the Adult Industry: The direct trade contribution of the adult industry is more concealed. Overseas sales of adult videos and games constitute its primary form. Although this revenue is often categorised under 'other services' or 'royalties and licence fees,' making it difficult to isolate, its scale is considerable. Industry estimates suggest the overseas market for the AV industry alone could reach hundreds of billions of yen. This revenue attracts foreign tourists, driving local transport, hotel occupancy, and souvenir sales, creating a perfect synergy between 'content and tourism.'

Elevating Brand Value Across Industries: The overall enhancement of the 'Cool Japan' image imbues traditional Japanese products (such as washoku cuisine, tea ceremony, and katana swords) and modern goods (like automobiles and electronics) with cultural value-added attributes like 'fashionable,' 'refined,' and 'discerning' in the minds of overseas consumers, thereby indirectly boosting exports of these products.

Catalysing Associated Industries:

Fostering Technology and Media Sectors: To meet filming and distribution demands, the AV industry has driven the adoption and advancement of technologies including high-definition camera systems, post-production software, streaming platforms, and VR/AR applications. These spillover effects have catalysed progress within Japan's related technology sectors.

Boosting advertising and publishing: The adult content industry requires substantial advertising and magazine publishing, providing stable advertising revenue and circulation for related media platforms. This sustains a vast subcultural media

ecosystem.

Stimulating specific consumer markets: The fan economy surrounding AV actresses has spawned a range of consumption, including photobooks, fan meetings, and merchandise. This has formed a unique internal market, with some products also finding their way overseas.

### 2.3 Nation Branding: The Double-Edged Sword of Soft Power

Industrial exports inherently constitute cultural and value transmission, exerting profound and complex influences on national image.

Animation: Shaping Positive Perceptions: The anime industry stands as Japan's most successful instrument of cultural diplomacy. It presents the world with an image of Japan as a nation brimming with creativity and vitality, seamlessly blending tradition with modernity. The universal values embodied in its works—friendship, perseverance, triumph—alongside distinctive Japanese aesthetics, effectively counteract negative perceptions stemming from historical issues. This has cultivated global affinity and goodwill towards Japanese culture (with the exception of China, in the author's view). This 'goodwill dividend' derived from cultural soft power is unmatched by any commercial advertising, creating a more favourable public opinion environment for Japanese enterprises expanding into overseas markets.

Sex Industry: Source of Negative Perception and Subcultural Appeal: The impact of Japan's sex industry on its national image is a double-edged sword <sup>[5]</sup>. On one hand, international criticism regarding Japan's 'developed sex industry' and 'objectification of women' persists, undermining its image as a serious developed nation and potentially providing moral grounds for condemnation by certain countries or organisations. Conversely, within subcultural circles, Japan's 'open' and "diverse" sexual culture exerts a unique appeal, satisfying certain overseas groups' curiosity and desire to explore exotic cultures. This image is fractured: a negative label in mainstream discourse, yet a cultural symbol within specific communities. This complexity often leads Japan to adopt a strategy of 'selective presentation' in its external communications.

## 3.Challenges and Controversies Facing the Sex Industry and Anime Industry

While generating substantial economic benefits for Japan, these two industries also present profound social, legal, and ethical challenges.

### 3.1 The Anime Industry's Dilemma: Stagnant Innovation and Talent Shortages

The Drawbacks of the Production Committee System: Although the 'production committee' model disperses risk, it also leads to issues such as overly lengthy profit chains, diminished creative autonomy for artists, and increasingly conservative content <sup>[6]</sup>. To cater to market demands, a flood of homogenised 'isekai' (alternate world) works has emerged, severely diminishing originality and potentially undermining long-term global competitiveness.

'Exploitative Companies' and Talent Shortage: The animation sector is notorious for low wages and high-intensity labour. The lack of safeguards for grassroots animators and creators has led to severe talent drain and a critical shortage of successors. This unsustainable model is eroding the very creative foundations upon which the industry relies.

Overseas Market Dependency and Risks: As the proportion of overseas markets continues to grow, Japan's anime industry faces external risks including geopolitical tensions, cultural differences, and rampant piracy. Any instability in major overseas markets could inflict substantial damage on the entire sector.

### 3.2 Ethical Dilemmas and Social Costs of the Sex Industry

Human Rights and Exploitation: This constitutes the most contentious aspect of the sex industry. Despite legal constraints, issues such as coercion, deception, and human trafficking persist within the adult entertainment sector. Practitioners, particularly women, face substantial physical and psychological risks alongside societal discrimination. The underlying social costs—including public health, policing, and victim support—ultimately fall upon society as a whole.

Disconnect Between Law and Reality: The vagueness of the Anti-Prostitution Law complicates regulation, allowing deep organised crime involvement and fostering corruption. This situation, where the law fails to punish the many, undermines legal authority and creates fertile ground for criminal activity.

Negative Image Consolidation: Excessive exposure of the sex industry risks cementing stereotypical, one-dimensional negative perceptions of Japan abroad. This undermines the positive national image painstakingly cultivated by sectors like

anime, potentially disrupting Japan's international relations and diplomatic endeavours.

## **4. Insights for China from Japan's Two Major Industries**

The developmental trajectories of Japan's two major industries offer valuable lessons for China in advancing the internationalisation of its cultural industries and balancing social benefits with economic returns.

### **4.1 Cultivating Content IP to Build a Full Industry Chain Ecosystem**

China possesses abundant historical and cultural resources alongside a vast domestic market, yet lags behind Japan in global IP operations and industrial chain extension. Key insights include:

**Shifting from 'Traffic-Centric Thinking' to 'IP-Centric Thinking':** Rather than settling for short-term online popularity, China should emulate Japan by meticulously cultivating core IPs with enduring vitality and universal appeal. This necessitates respecting creative principles while affording creators sufficient patience and remuneration.

**Refining the Industrial Chain:** Adopt Japan's 'multi-platform exploitation' model by systematically developing successful IPs into diverse products such as animation, films, games, merchandise, and physical experiences. This maximises value while stimulating exports in related manufacturing and service sectors.

**Combining Government Guidance with Market Driven Forces:** Drawing from the 'Cool Japan' strategy, governments can provide policy, funding, and overseas promotion support. However, market principles must be respected to prevent excessive intervention that stifles content innovation.

### **4.2 Balancing Cultural Exportation and Social Values**

Japan's experience demonstrates that cultural exportation is a double-edged sword. As China advances its cultural outreach, it must navigate the following relationships:

**Balancing 'localisation' and 'globalisation':** Outstanding cultural products must be rooted in domestic cultural soil while adeptly employing international narrative and audiovisual languages. They should resonate emotionally with global audiences, avoiding heavy-handed didacticism.

**Upholding cultural boundaries to guard against negative impacts:** Clear censorship and rating systems must govern sensitive content such as sexuality and violence. Japan's contentious sex industry serves as a cautionary tale that economic gains should not come at the expense of social order, public morals, or a nation's long-term image. Social benefits must take precedence in cultural industry development.

**Proactively shaping national image:** Rather than passively allowing industries to develop organically, proactive planning and guidance are essential. Through cultural products, we must effectively tell the 'Chinese story,' crafting a credible, endearing, and respectable image of China that serves the nation's overarching strategy.

### **4.3 Prioritising industry health and safeguarding practitioners' rights**

The talent crisis in Japan's anime sector and the plight of workers in its sex industry both underscore the critical importance of sustainable industrial development.

**Establishing a Healthy Industry Ecosystem:** Market order must be regulated, piracy combated, and intellectual property protected to ensure creators and practitioners receive fair remuneration. Improving working conditions and establishing talent development systems form the bedrock of long-term cultural industry prosperity.

**Strengthening Legal Oversight and Social Governance:** All industries must operate within the rule of law. China should refine relevant legislation, clarify industry boundaries, rigorously combat illegal activities, protect vulnerable groups, and uphold social fairness and justice.

## **Conclusion**

The sex industry and the anime industry—two sectors occupying vastly different positions within Japanese society—have nonetheless jointly shaped the contemporary landscape of Japan's foreign trade in their own distinct ways. As the flagship of Japan's cultural soft power, the anime industry, with its formidable IP creativity and global reach, has generated significant economic surpluses and fostered a positive national image, serving as a crucial pillar for Japan's sustained trade competitiveness in the post-industrial era. Meanwhile, the sex industry, operating within a grey area, functions as a complex

‘shadow economy’. By fostering associated content industries and attracting specific tourism, it contributes a covert yet undeniable force to Japan’s trade balance, while simultaneously posing profound social ethical challenges and risks to its image <sup>[7]</sup>.

A comparative analysis of these two sectors reveals several critical trends in contemporary international trade: firstly, the growing prominence of intangible trade centred on culture, creativity, and experiential value; secondly, the increasingly blurred boundaries between industries, with deep integration across culture, technology, tourism, and services forming complex industrial ecosystems; thirdly, the tension between economic interests, social values, and national image has become a core issue requiring careful balancing in national industrial policy formulation.

For China, striving to become a cultural powerhouse and drive high-quality economic development, Japan’s experiences offer profound lessons. We must learn from its successes in creating global intellectual property and building comprehensive industrial chains, while remaining vigilant against issues such as industrial hollowing-out, talent drain, and high societal costs. Ultimately, a nation’s true strength in foreign trade lies not merely in the scale of its trade surplus, but in the underlying cultural creativity, social governance capabilities, and sustainable, healthy ecosystem that underpin it. While pursuing economic gains, upholding cultural confidence and maintaining fundamental values to achieve a harmonious balance between economic and social benefits represents the enduring path for China’s cultural industries to thrive globally.

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# Understanding University Students' Green Purchase Behaviour

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**Abstract:** In recent years, universities have increasingly been treated as everyday laboratories for greener lifestyles, yet the link between what students say about the environment and what they actually buy is still quite uncertain. This study applies the Theory of Planned Behaviour to examine how Subjective Norms and Perceived Behavioural Control are connected to Green Consumption Attitude, Green Buying Intention and Green Purchase Behaviour among university students in China. Based on 181 valid questionnaires and analyses conducted with PROCESS Model 6, the findings suggest that both Subjective Norms and Perceived Behavioural Control are linked to more positive attitudes toward green consumption and higher levels of purchase intention. Green Buying Intention is found to be the most stable predictor of behaviour, whereas Green Consumption Attitude alone neither shows a significant direct effect nor serves as an effective single mediator. In most cases, the two predictors influence behaviour through a stepwise route in which changes in attitude are followed by shifts in intention and, only after that, by actual purchasing. This sequential pattern underlines the importance of intention in explaining why supportive environmental views do not always lead to consistent green actions, and it provides a basis for universities, public agencies and businesses to design more targeted measures that make green choices easier and more attractive for students.

**Keywords:** Green Consumption Attitude; Subjective Norms; Perceived Behavioural Control; Green Buying Intention; Green Purchase Behaviour; Theory of Planned Behaviour; University Students

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## 1.Introduction

Sustained pressure on natural resources and the continuing deterioration of environmental quality have pushed sustainability and green transition to the centre of policy discussions in many countries <sup>[1][2]</sup>. Governments are increasingly incorporating green lifestyles, lower-impact patterns of consumption and carbon-reduction measures into medium- and long-term development plans. Against this backdrop, China's dual-carbon strategy has brought green consumption to the foreground



as a basic pillar of ecological civilisation construction<sup>[3]</sup>. Green consumption now carries several tasks at once: it eases pressure on resources, supports environmental governance and facilitates adjustments in the structure of the economy, while also nudging growth trajectories toward lower-carbon modes<sup>[4][5]</sup>. Creating social conditions in which green consumption is widely recognised and routinely practised has therefore become a critical link in the chain leading to national carbon-reduction targets<sup>[6][7]</sup>.

Among different social groups, younger generations hold a particularly prominent position in this shift toward greener ways of living, and university students form one of the most influential subgroups. Compared with many other consumers, they typically possess stronger educational backgrounds, respond more quickly to information and display heightened sensitivity to environmental problems. As a result, their attitudes towards green ideas are often relatively open and forward-looking<sup>[8][9]</sup>. On campus, everyday consumption does more than shape their own lifestyles. Through routine interaction and imitation, students' choices can influence classmates and family members, forming a chain through which green behaviour gradually spreads to wider social circles<sup>[7][9]</sup>.

At the same time, existing studies repeatedly point to a clear mismatch between students' attitudes and their actions. Many university students agree that green consumption is important, yet their actual purchasing behaviour falls short of their stated values<sup>[10][11]</sup>. Practical barriers play a part in this. Higher prices, limited purchasing channels on or near campus and the difficulty of assessing the credibility of eco-labels all make it harder for students to act consistently with their environmental beliefs, and green ideals are therefore not always translated into everyday decisions<sup>[1][12]</sup>.

To understand this attitude-behaviour gap more clearly, it is necessary to examine how students' green attitudes, intentions and behaviours differ, and which factors influence the conversion of intention into action<sup>[10][13]</sup>. The present study takes university students' green attitudes and behaviours as its main focus and adopts the Theory of Planned Behaviour (TPB) as the underlying analytical framework. By incorporating attitude, subjective norms and perceived behavioural control, TPB makes it possible to analyse, in a systematic way, how green consumption intentions are formed and how they are (or are not) reflected in actual behaviour, as well as how the attitude-behaviour gap manifests in this specific group<sup>[14][6]</sup>. As a classic framework for explaining behavioural change, TPB fits well with the characteristics of green purchasing and helps address the relative lack of research on youth subgroups in this field<sup>[14][11]</sup>.

The significance of students' green purchasing behaviour goes beyond campus-based environmental activities. As a future core consumer group, their values and consumption patterns are likely to influence broader market trends. If students are able to maintain green habits over the long term, this can reduce resource wastage and contribute to environmental improvement, while also encouraging families and communities to experiment with greener lifestyles through everyday interaction and example<sup>[2][8]</sup>. Repeated exposure to and participation in green consumption can also deepen students' sense of environmental responsibility and gradually orient their values toward more sustainable choices. Such value shifts are likely to influence the kinds of options they make and the ways they engage in public life after graduation, once they move from campus into broader society<sup>[6][7]</sup>.

## 2. Literature Review and Research Hypotheses

### 2.1 Green Consumption Attitude

Green Consumption Attitude (GCA) describes the general way individuals judge green products and the environmental benefits associated with them, and is usually regarded as a key antecedent in the Theory of Planned Behaviour<sup>[14]</sup>. Among university students, this attitude tends to grow out of several underlying concerns, such as attention to personal health, a felt responsibility for the natural environment and the degree to which green practices appear consistent with their own values and the values they perceive around them<sup>[6]</sup>. Studies in recent years point to a gradual strengthening of students' support for green consumption, helped by the wider promotion of green lifestyles, the increasing presence of green products and more frequent communication of policy messages related to sustainability<sup>[8]</sup>.

The settings in which students live and study can also shape how GCA takes form. When family members, peers or online networks send repeated positive signals about green consumption, students are more inclined to develop favourable views of green products and to see them as a reasonable choice in everyday life<sup>[9]</sup>. Concrete conditions matter as well: whether such

products are easy to obtain, fall within an acceptable price range and can be reliably identified through labels all influence how positive their attitudes become <sup>[1][4]</sup>. Taken together, these findings indicate that GCA arises from both personal cognitive evaluations and the combined effects of social norms and perceived behavioural control. On this basis, the following hypothesis is proposed:

H3: Green Consumption Attitude (GCA) positively influences Green Buying Intention (GBI).

## 2.2 Subjective Norms

Subjective Norms (SN) describe the expectations that students perceive from significant others and from the wider social environment when they make consumption decisions, and they constitute an important source of social pressure around green choices <sup>[8]</sup>. In university settings, peer influence, the broader campus climate and green-related content on social media all contribute, to varying degrees, to shaping students' willingness to support green products <sup>[7][9]</sup>. For example, when green-themed events, public campaigns or classmates' pro-environmental actions become visible on campus, they often create a demonstration effect that makes students more inclined to adopt green purchasing patterns themselves <sup>[7]</sup>.

SN do not only matter for attitudes; they can also work through intention to influence actual Green Purchase Behaviour (GPB) <sup>[11]</sup>. When the surrounding social environment sends clear and positive signals in favour of green consumption, students are more likely to develop Green Buying Intention (GBI) and then act on it in real situations <sup>[13]</sup>. Recent studies further point to a chained mechanism in which social expectations first shape attitudes toward green consumption, these attitudes then reinforce purchase intentions and, in turn, intentions give rise to behaviour <sup>[15]</sup>. Building on this line of reasoning, the following hypotheses are proposed:

H1: Subjective Norms (SN) positively influence Green Consumption Attitude (GCA).

H5: Subjective Norms (SN) indirectly influence Green Purchase Behaviour (GPB) through Green Consumption Attitude (GCA).

H6: Subjective Norms (SN) indirectly influence Green Purchase Behaviour (GPB) through Green Buying Intention (GBI).

H7: Subjective Norms (SN) influence Green Purchase Behaviour (GPB) through the sequential mediation of Green Consumption Attitude (GCA) and Green Buying Intention (GBI).

## 2.3 Perceived Behavioural Control

Perceived Behavioural Control (PBC) describes how students judge their own ability to carry out a particular behaviour, including whether they have enough time, money, knowledge and practical convenience to do so <sup>[1]</sup>. In green consumption settings, this judgement is closely tied to how students view green product prices, how easily such products can be purchased and whether environmental labels are clear and recognisable. When prices seem acceptable, products are not hard to find and labels are easy to understand, green consumption is seen as manageable rather than burdensome, and students tend to report more positive attitudes and stronger intentions toward green choices <sup>[3]</sup>.

Within explanations of green purchasing, PBC usually enters the model as an important driver that shapes attitudes, intentions and behaviour at the same time. Empirical work finds that students who feel they have greater control are more likely to develop favourable views of green consumption and to include green products in their future spending plans <sup>[15]</sup>. Recent mediation-oriented studies further point to a stepwise pattern: higher perceived control can first lift attitudes, which then reinforce purchase intentions and, in a later stage, increase the probability that green purchasing behaviour will actually take place <sup>[13]</sup>. On this basis, the study proposes the following hypotheses:

H2: Perceived Behavioural Control (PBC) positively influences Green Consumption Attitude (GCA).

H8: Perceived Behavioural Control (PBC) indirectly influences Green Purchase Behaviour (GPB) through Green Consumption Attitude (GCA).

H9: Perceived Behavioural Control (PBC) indirectly influences Green Purchase Behaviour (GPB) through Green Buying Intention (GBI).

H10: Perceived Behavioural Control (PBC) influences Green Purchase Behaviour (GPB) through the sequential mediation of Green Consumption Attitude (GCA) and Green Buying Intention (GBI).

## 2.4 Green Purchase Intention

Green Purchase Intention (GBI) describes an individual's planned tendency to buy green products or to engage in environmentally friendly actions in the future, and it occupies a central mediating position in most models of green behaviour<sup>[13]</sup>. Existing studies generally find that when students hold more positive views of green products, they also report stronger intentions to purchase them<sup>[11]</sup>. In this sense, GBI plays a connecting role in the formation of green behaviour: it is shaped by prior attitudes and, at the same time, serves as an important predictor of actual Green Purchase Behaviour (GPB)<sup>[15]</sup>.

Because intention is often the step that converts attitudes into concrete action, students with stronger green purchase intentions are more likely, in everyday consumption, to choose environmentally friendly products, reduce their use of disposable items or take part in environmental activities<sup>[15]</sup>. Against this background, the analysis pays particular attention to how Green Consumption Attitude operates as an antecedent of intention. On this basis, the following hypothesis is put forward:

H4: Green Buying Intention (GBI) positively influences Green Purchase Behaviour (GPB).

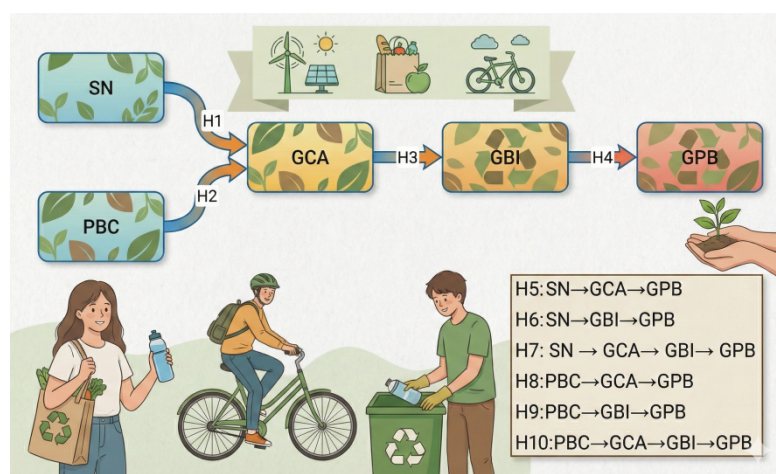
## 2.5 Green Purchase Behaviour

Green Purchase Behaviour (GPB) refers to the concrete actions through which consumers put green consumption into practice, for example buying environmentally friendly products, avoiding single-use items, choosing energy-saving appliances or supporting brands that stress sustainability<sup>[10]</sup>. Within the Theory of Planned Behaviour (TPB), Green Purchase Behaviour (GPB) usually appears at the end of the explanatory chain and is shaped jointly by Green Consumption Attitude (GCA), Subjective Norms (SN), Perceived Behavioural Control (PBC) and Green Buying Intention (GBI)<sup>[14]</sup>.

Recent work also reminds that strong environmental concern does not automatically lead to consistent green purchasing among university students. In daily consumption, decisions are filtered through a series of practical considerations: green products often cost more, the reliability of eco-labels is sometimes questioned, suitable products are not always easy to find and conventional alternatives remain widely available and convenient<sup>[1][12]</sup>. At the same time, campus initiatives, the visible environmental conduct of teachers and peers and the steady flow of green messages on social media can gently push students in the opposite direction, making green options more noticeable and keeping environmental issues on their agenda<sup>[9][7]</sup>.

Taken together, GPB captures the actual choices students make on the basis of their green values, while also reflecting the pressures and constraints of their social and material environment. Exploring how GPB is formed helps clarify how attitudes and intentions are—or are not—translated into action, and provides useful reference points for universities and other institutions seeking to encourage more sustainable consumption among young people. The overall research model used in this study is summarised in Figure 1.

Figure3: Research Model



## 3. Research Methods and Data Analysis

### 3.1 Research Methods and Design

The study uses a quantitative research design and focuses on students currently studying in Chinese higher education, including higher vocational colleges, undergraduate programmes and master's and doctoral courses<sup>[16]</sup>. Data were gathered

through an online questionnaire built on the Wenjuanxing platform and distributed by convenience sampling via university social media groups and peer forwarding. After questionnaires were returned, incomplete or clearly invalid responses were removed, and the remaining valid cases were used for the empirical analysis<sup>[14]</sup>.

The survey was divided into two main sections. The first collected background information, including gender, year of study, type of institution and monthly living expenses. The second section comprised the core measurement scales for Subjective Norms (SN), Perceived Behavioural Control (PBC), Green Consumption Attitude (GCA), Green Buying Intention (GBI) and Green Purchase Behaviour (GPB)<sup>[17][18]</sup>. Most items were drawn from classic TPB-based instruments and prior green consumption studies, then slightly adapted to fit the linguistic and cultural context of Chinese university students. All items were rated on a five-point Likert scale (1 = strongly disagree, 5 = strongly agree) to ensure that respondents could understand and answer the questions with relative ease.

For the data analysis, SPSS 27 was used to organise and test the survey responses in a systematic way. The analysis started with descriptive statistics to outline the basic features of the sample and to observe how the main variables were distributed overall. Next, Cronbach's alpha was applied to assess the internal consistency of each scale. Only after the reliability indices reached an acceptable level was Exploratory Factor Analysis (EFA) carried out, in order to check whether the items clustered onto the constructs as expected and to evaluate the structural validity of the scales.

Once the measurement checks were completed, Pearson correlation coefficients were computed to examine the basic linear relationships among Subjective Norms (SN), Perceived Behavioural Control (PBC), Green Consumption Attitude (GCA), Green Buying Intention (GBI) and Green Purchase Behaviour (GPB). Before testing the main regression paths, background variables such as gender and monthly living expenses were also subjected to group comparison tests to see whether students with different characteristics showed significant differences in GCA, GBI and GPB. These results were then used to decide whether such variables should be included as controls in the subsequent models.

To test the statistical validity of the "dual-mediation" framework, the study finally employed the PROCESS macro (Model 6). In this specification, SN and PBC were treated as independent variables, GCA and GBI as serial mediators and GPB as the dependent variable. A bias-corrected bootstrap procedure was used to repeatedly resample the data and estimate indirect effects and their 95% confidence intervals, providing a basis for judging whether the individual mediation paths and the sequential mediation effects were statistically significant.

### 3.2 Descriptive Statistical Analysis

In total, 218 questionnaires were distributed and 203 were returned. After removing incomplete or clearly invalid responses, 181 valid cases were kept for analysis. Among these respondents, 116 were female, accounting for 64.1 % of the sample, and 65 were male (35.9 %). This gender split is broadly in line with what is often seen in university-based surveys.

With regard to study level, undergraduates made up the bulk of the respondents: 142 students, or 78.5 % of the sample. There were also 26 higher vocational students (14.4 %), eight master's students (4.4 %) and five doctoral students (2.8 %). Overall, the educational structure largely reflects the usual hierarchy found in Chinese universities, where undergraduate enrolment is dominant.

Monthly living expenses were mainly clustered in the middle band. Most students ( $n = 130$ , 71.8 %) reported spending between 1,500 and 3,000 yuan per month. A smaller group of 30 students (16.6 %) had living expenses of 1,500 yuan or below, while 12 students (6.6 %) fell in the 3,000–6,000 yuan range. Only nine respondents (5.0 %) reported monthly expenses above 6,000 yuan. This pattern suggests that the majority of respondents are situated around a moderate spending level, which matches the general consumption situation of many university students.

Overall, the sample is dominated by undergraduate students, and the observed distributions for gender, education level and living expenses are broadly consistent with the characteristics of typical student populations, providing a reasonably sound basis for the analyses that follow.

### 3.3 Reliability and Structural Validity Testing

Before looking at the main hypotheses, the quality of the measurement scales was checked in terms of both reliability and structure. Internal consistency was assessed with Cronbach's  $\alpha$ , which shows whether items intended to measure the same

construct move together in a reasonably similar way<sup>[19][20][21]</sup>.

Structural validity was examined using several commonly reported indicators. The Kaiser–Meyer–Olkin (KMO) statistic was used to judge whether the data were suitable for factor extraction, and Bartlett’s test of sphericity was applied to see whether the correlation matrix differed sufficiently from an identity matrix. Based on these preliminary checks, an Exploratory Factor Analysis (EFA) was then conducted to see how the items grouped in practice and whether this pattern was in line with the theoretical structure of the constructs<sup>[22]</sup>. The outcomes of these tests were used as a basic quality check before proceeding to the later modelling steps.

*Table 1. Reliability and Validity Summary*

Variable	Items	Cronbach’s $\alpha$	KMO	Bartlett’s Test ( $\chi^2$ , df, p)	Overall Assessment
GCA (Green Consumption Attitude)	4	0.897	0.842	$\chi^2 = 423.291$ , df = 6, $p < .001$	Reliability and validity are good
SN (Subjective Norms)	5	0.881	0.878	$\chi^2 = 443.400$ , df = 10, $p < .001$	Good reliability and validity
PBC (Perceived Behavioural Control)	4	0.855	0.809	$\chi^2 = 310.389$ , df = 6, $p < .001$	Good reliability and validity
GBI (Green Purchase Intention)	3	0.788	0.696	$\chi^2 = 162.499$ , df = 3, $p < .001$	Acceptable, meets basic standards
GPB (Green Purchase Behaviour)	4	0.814	0.79	$\chi^2 = 231.831$ , df = 6, $p < .001$	Good reliability and validity

As shown in Table 1, the reliability indicators are satisfactory. The Cronbach’s  $\alpha$  values for Green Consumption Attitude (GCA), Subjective Norms (SN), Perceived Behavioural Control (PBC) and Green Purchase Behaviour (GPB) are all above 0.80, which points to good internal consistency for these four scales. Green Buying Intention (GBI) has an  $\alpha$  of 0.788. Although this is slightly lower than the others, it is still above the usual cut-off of 0.70 often used in social science studies, so the reliability of this construct can be regarded as acceptable. On this basis, all five core variables meet the basic requirements for subsequent statistical analysis.

For structural validity, the KMO statistics fall between 0.696 and 0.878. Apart from GBI, whose KMO value of 0.696 is marginally below 0.70 yet still close to that benchmark, the remaining variables fall within the moderate to good range. In addition, Bartlett’s test of sphericity is significant at the  $p < .001$  level for all scales, indicating that the correlation matrices differ significantly from an identity matrix and that factor analysis is appropriate. Taken together, the reliability and validity results show that the scales used in this study possess satisfactory internal coherence and a reasonably stable factor structure, providing a sound basis for subsequent confirmatory analyses and mediation modelling.

### 3.4 Correlations Among Key Variables

To improve the accuracy of the subsequent model estimation, the analysis first considered whether students with different background characteristics scored differently on the main variables. In particular, mean scores on Green Consumption Attitude (GCA), Subjective Norms (SN), Perceived Behavioural Control (PBC), Green Buying Intention (GBI) and Green Purchase Behaviour (GPB) were compared between male and female students and across groups with different levels of monthly living expenses. Where clear group differences exist, these background factors need to be treated as control variables in later models so that they do not distort the relationships among the core constructs. The difference tests therefore serve mainly to decide whether such background variables should enter the mediation analysis as controls, thereby improving the precision of model interpretation.

Before turning to these group comparisons, the Pearson correlation matrix was examined to gain an initial view of the direction and strength of associations among the key variables. As reported in Table 2, GCA is positively and significantly related to SN, PBC, GBI and GPB ( $p < .01$ ), with correlation coefficients ranging from .752 to .871. SN also shows strong positive correlations with the other constructs, all above .786, and the links among PBC, GBI and GPB are likewise highly significant. These patterns indicate a set of stable, mutually reinforcing positive relationships among the five core variables, consistent with theoretical.



Table 2. Pearson Correlation Matrix

Variable	GCA	SN	PBC	GBI	GPB
GCA (Green Consumption Attitude)	1	.871**	.793**	.768**	.752**
SN (Subjective Norms)	—	1	.819**	.816**	.786**
PBC (Perceived Behavioural Control)	—	—	1	.812**	.804**
GBI (Green Purchase Intention)	—	—	—	1	.830**
GPB (Green Purchase Behaviour)	—	—	—	—	1

Notes: N = 181. All correlations significant at the 0.01 level (two-tailed). “—” indicates values omitted due to matrix symmetry (upper triangular matrix only).

### 3.5 Difference Testing of Background Variables

To see whether students with different backgrounds respond differently on the green-consumption variables, three sets of comparisons were carried out for gender, educational level and monthly living expenses. Because gender includes only two groups, it was examined using an independent samples t-test<sup>[23]</sup>, whereas educational level and monthly living expenses, which contain multiple categories, were analysed using One-Way ANOVA to test for between-group differences<sup>[24]</sup>.

As reported in Table 3, female respondents score higher than males on all five key variables—Green Consumption Attitude (GCA), Subjective Norms (SN), Perceived Behavioural Control (PBC), Green Buying Intention (GBI) and Green Purchase Behaviour (GPB)—and these differences are statistically significant at  $p < .05$ . The effect sizes are also substantial, with Cohen’s  $d$  ranging from 0.96 to 1.02, indicating a large practical impact. In other words, compared with male students, female students tend to hold more positive attitudes toward green consumption, perceive stronger social expectations, feel more able to act in environmentally friendly ways, express clearer purchase intentions and engage more actively in green purchasing.

Table 3. Gender Differences: Independent Samples t-Test

Variable	Male Mean (n=65)	Female Mean (n=116)	t	p	Cohen’s d	Conclusion
GCA (Green Consumption Attitude)	3.52	4.23	-4.52	< .001	1.02	Higher in females
SN (Subjective Norms)	3.51	4.08	-3.74	< .001	0.97	Higher in females
PBC (Perceived Behavioural Control)	3.37	3.83	-2.93	0.004	1.02	Higher in females
GBI (Green Purchase Intention)	3.39	3.84	-2.86	0.005	1.02	Higher in females
GPB (Green Purchase Behaviour)	3.5	3.86	-2.4	0.018	0.96	Higher in females

A further look at Table 4 shows clear differences across educational levels. The One-Way ANOVA results indicate that higher vocational students, undergraduates and postgraduates score differently on all five main variables, with F values ranging from 12.812 to 31.174 and all p-values below .001. In practical terms, students with more advanced educational backgrounds tend to show more developed green values, a sharper sensitivity to social expectations and more consistent patterns of green consumption behaviour. Variations in academic training, the depth of environmental knowledge and differences in how students approach and process information are likely to contribute to these group distinctions.

Table 4. One-Way ANOVA for Education Level

Variable	F	p	Conclusion
GCA (Green Consumption Attitude)	31.174	< .001	Significant differences between groups
SN (Subjective Norms)	19.194	< .001	Significant differences
PBC (Perceived Behavioural Control)	16.847	< .001	Significant differences
GBI (Green Purchase Intention)	12.989	< .001	Significant differences
GPB (Green Purchase Behaviour)	12.812	< .001	Significant differences



Table 5 reports the differences across monthly living expense groups. All five core variables vary significantly by expenditure level ( $p < .05$ ). Students with higher living allowances generally have more discretionary income, making it easier for them to set aside money for green products; at the same time, their value orientations and consumption habits appear more inclined towards supporting environmentally responsible options. These findings suggest that family economic conditions, to some extent, shape how students view green consumption, how willing they are to act on it, and how steadily they maintain green purchasing behaviour.

Table 5. One-Way ANOVA for Monthly Living Expenses

Variable	F	p	Conclusion
GCA (Green Consumption Attitude)	5.508	0.001	Significant group differences
SN (Subjective Norms)	4.565	0.004	Significant differences
PBC (Perceived Behavioural Control)	2.893	0.037	Significant differences
GBI (Green Purchase Intention)	3.907	0.01	Significant differences
GPB (Green Purchase Behaviour)	4.052	0.008	Significant differences

Taken together with the earlier results, it is clear that gender, educational level and monthly living expenses all exert significant influence on students' scores for GCA, SN, PBC, GBI and GPB.

### 3.6 Empirical Examination of the Mediation Model

#### 3.6.1 Effects of Independent Variables on Mediators and Outcome Variables (Direct Effects)

To examine how Subjective Norms (SN) and Perceived Behavioural Control (PBC) operate within the model, the analysis first focuses on their direct effects on Green Consumption Attitude (GCA), Green Buying Intention (GBI) and Green Purchase Behaviour (GPB). The corresponding estimates are reported in Table 6, with separate panels for the SN and PBC models. This layout allows the direct links from each independent variable to the two mediators and to the behavioural outcome to be viewed and compared in a straightforward way.

Table 6. Main Effects Regression Results (SN and PBC Models)

Path	$\beta$	SE	t	p	95% CI
SN $\rightarrow$ GCA	0.9304	0.0392	23.7396	< .001	[0.8531, 1.0078]
SN $\rightarrow$ GBI	0.6271	0.0891	7.0413	< .001	[0.4513, 0.8028]
GCA $\rightarrow$ GBI (SN model)	0.2281	0.0834	2.7353	0.0069	[0.0635, 0.3926]
SN $\rightarrow$ GPB (direct effect)	0.2042	0.0872	2.3423	0.0203	[0.0322, 0.3762]
GBI $\rightarrow$ GPB (SN model)	0.5072	0.0649	7.8167	< .001	[0.3792, 0.6353]
PBC $\rightarrow$ GCA	0.8229	0.0472	17.4242	< .001	[0.7297, 0.9161]
PBC $\rightarrow$ GBI	0.5486	0.0673	8.1516	< .001	[0.4158, 0.6814]
GCA $\rightarrow$ GBI (PBC model)	0.3202	0.0649	4.937	< .001	[0.1922, 0.4482]
PBC $\rightarrow$ GPB (direct effect)	0.2867	0.0685	4.1824	< .001	[0.1514, 0.4219]
GBI $\rightarrow$ GPB (PBC model)	0.4361	0.0651	6.6948	< .001	[0.3076, 0.5647]

In the SN model, Subjective Norms (SN) show a strong, positive effect on Green Consumption Attitude (GCA) ( $\beta = 0.9304$ ,  $p < .001$ ). When students feel that family members, friends or other important groups expect them to consume in a more environmentally friendly way, their overall evaluation of green consumption becomes noticeably more favourable. In the SN model, Subjective Norms (SN) also show a clear direct effect on Green Buying Intention (GBI) ( $\beta = 0.6271$ ,  $p < .001$ ). When students feel that people around them expect them to consume in a greener way, they are more likely to plan to buy green products. Green Consumption Attitude (GCA) is likewise a significant predictor of GBI ( $\beta = 0.2281$ ,  $p = .0069$ ), which means

that more favourable views of green consumption tend to go hand in hand with stronger intentions to purchase such products. At the behavioural level, SN continues to play a role. Its direct effect on Green Purchase Behaviour (GPB) remains significant ( $\beta = 0.2042$ ,  $p = .0203$ ), while the coefficient for GBI is even larger ( $\beta = 0.5072$ ,  $p < .001$ ). These results indicate that intention stands closest to actual behaviour in the overall chain and has substantial weight in explaining whether green purchases take place.

The PBC model points in a similar direction. Perceived Behavioural Control (PBC) has a significant positive effect on GCA ( $\beta = 0.8229$ ,  $p < .001$ ), suggesting that students who believe they have enough time, money, information or convenience to act in an environmentally friendly way tend to hold more positive attitudes toward green consumption. PBC also predicts GBI ( $\beta = 0.5486$ ,  $p < .001$ ), implying that a stronger sense of being able to act makes students more likely to plan green purchases. In this model, GCA once again shows a significant association with GBI ( $\beta = 0.3202$ ,  $p < .001$ ), confirming that attitude remains an important part of intention formation.

For GPB, PBC's predictive effect is likewise significant ( $\beta = 0.2867$ ,  $p < .001$ ), implying that higher perceived capability is associated with both stronger willingness and more frequent green purchasing in practice. GBI continues to show a robust positive effect on GPB ( $\beta = 0.4361$ ,  $p < .001$ ), consistent with the SN model.

Taken together, both SN and PBC significantly affect GCA, GBI and ultimately GPB, and the direction of these links fits well with the logic of the Theory of Planned Behaviour. Social expectations and perceived capability jointly shape students' attitudes and intentions and, through them, their actual purchasing choices. These direct-effect results provide a solid base for the subsequent tests of single and serial mediation.

### 3.6.2 Testing of Single Mediation Paths

To test whether Subjective Norms (SN) and Perceived Behavioural Control (PBC) indirectly shape Green Purchase Behaviour (GPB) via Green Consumption Attitude (GCA) or Green Buying Intention (GBI), the study applied a bootstrap-based mediation analysis. Using 5,000 resamples, the indirect effects along each path were estimated and their confidence intervals derived. The detailed results of these single mediation tests are summarised in Table 7.

Table 7. Single Indirect Effects (SN and PBC Models)

Mediation Path	Effect	Boot SE	95% CI	Significance
SN → GCA → GPB	0.1309	0.0781	[-0.0326, 0.2722]	Not significant
SN → GBI → GPB	0.3181	0.0718	[0.1950, 0.4773]	Significant
PBC → GCA → GPB	0.1157	0.0623	[-0.0064, 0.2432]	Not significant
PBC → GBI → GPB	0.2392	0.053	[0.1425, 0.3494]	Significant

In the SN model, the indirect effect for the path running from Subjective Norms (SN) to Green Purchase Behaviour (GPB) via Green Consumption Attitude (GCA) is 0.1309, with a 95 % bootstrap confidence interval of  $-0.0326$  to  $0.2722$ . Because the interval crosses zero, this mediation path is not statistically supported. In other words, stronger social expectations do raise GCA, but this attitudinal gain does not, by itself, bring about a stable increase in green purchasing.

By contrast, the path from SN to GPB through Green Buying Intention (GBI) shows clear evidence of mediation. The indirect effect is 0.3181, and the 95 % confidence interval of  $0.1950$  to  $0.4773$  lies entirely above zero. This pattern indicates that the influence of SN on behaviour operates mainly by reinforcing GBI, rather than through changes in attitude alone.

A comparable picture appears in the PBC model. The indirect effect of Perceived Behavioural Control (PBC) on GPB via GCA is 0.1157, with a confidence interval of  $-0.0064$  to  $0.2432$  that includes zero, so this route is not statistically significant. Even when students believe they possess the resources or ability needed for green consumption, improvements in attitude do not reliably translate into actual purchasing. In contrast, the pathway from PBC to GPB mediated by GBI is significant: the indirect effect is 0.2392, and the confidence interval of  $0.1425$  to  $0.3494$  excludes zero. A stronger sense of behavioural control therefore tends to foster purchase intentions, which subsequently raise the probability of engaging in green purchasing.

Across both models, only the intention-based mediation paths are consistently significant, whereas the attitude-based paths fail to reach statistical significance. These results highlight the pivotal role of GBI in the development of green purchasing behaviour and accord with the Theory of Planned Behaviour, which treats intention as the most immediate determinant of action.

### 3.6.3 Testing of the Sequential Mediation Path

To clarify whether Subjective Norms (SN) and Perceived Behavioural Control (PBC) shape Green Purchase Behaviour (GPB) through a stepwise psychological process in which Green Consumption Attitude (GCA) precedes Green Buying Intention (GBI), the analysis applied PROCESS Model 6 to test sequential mediation. Indirect effects were estimated using 5,000 bootstrap resamples, and the resulting coefficients and confidence intervals are summarised in Table 8.

*Table 8. Serial Mediation Effects from GCA through GBI to GPB*

Serial Path	Effect	Boot SE	95% CI	Significance
SN → GCA → GBI → GPB	0.1076	0.0534	[0.0022, 0.2142]	Significant
PBC → GCA → GBI → GPB	0.1149	0.0379	[0.0462, 0.1955]	Significant

In the SN model, the sequential mediation effect of Subjective Norms (SN) on Green Purchase Behaviour (GPB) via Green Consumption Attitude (GCA) and then Green Buying Intention (GBI) is 0.1076, with a 95 % bootstrap confidence interval of [0.0022, 0.2142]. Because the interval does not include zero, this chain is statistically significant. The result indicates that social expectations first shape students' overall attitudes towards green consumption, these more positive attitudes then strengthen their intention to buy green products, and the reinforced intention ultimately promotes greener purchasing behaviour.

In the PBC model, the sequential pathway from Perceived Behavioural Control (PBC) through GCA and GBI to GPB shows an indirect effect of 0.1149, with a 95 % bootstrap confidence interval of [0.0462, 0.1955], again entirely above zero. This pattern suggests that when students believe they have sufficient ability, resources or conditions to practise green consumption, they tend to develop more favourable attitudes. These more positive attitudes then feed into stronger purchase intentions, and students who report higher levels of intention are, in turn, more likely to engage in green purchasing in everyday life.

Looking across both models, a similar pattern appears. No matter whether the starting point is social pressure captured by Subjective Norms (SN) or a stronger sense of capability reflected in Perceived Behavioural Control (PBC), the influence on Green Purchase Behaviour (GPB) passes through the same chain: attitudes become more positive, intentions grow stronger and behaviour follows. Green Buying Intention (GBI) sits at the centre of this process as the main link between the psychological drivers and the eventual purchasing choices. This structure is highly consistent with the Theory of Planned Behaviour, which views intention as the closest step before action.

## 3.7 Summary of Hypothesis Testing Results

Across the analysis, both Subjective Norms (SN) and Perceived Behavioural Control (PBC) are linked with higher scores on Green Consumption Attitude (GCA), Green Buying Intention (GBI) and Green Purchase Behaviour (GPB). This suggests that what students think others expect of them, and how capable they feel of acting, are two important external forces behind green purchasing. At the same time, the mediation tests show an interesting imbalance. GCA does not emerge as a significant single mediator, whereas GBI plays a steady and comparatively stronger mediating role. In other words, many students agree with green ideas at the level of belief, but these beliefs rarely move straight into behaviour; it is intention that acts as the more decisive psychological driver<sup>[25][26]</sup>. The sequential mediation results add to this picture: once GCA is activated and then reinforces GBI, the two together form a psychological chain that supports the emergence of green purchasing behaviour<sup>[27]</sup>.

The direct-effect estimates point in the same direction. SN and PBC both show significant positive links with GCA (supporting H1 and H2), and higher levels of GCA are associated with stronger GBI (supporting H3). GBI, in turn, remains the most stable predictor of GPB (supporting H4), outlining a pathway through which intention channels internal motivation into observable behaviour. In the single mediation tests, the indirect paths via GBI are significant for both SN and PBC (supporting H6 and H9). By contrast, the indirect paths via GCA do not reach statistical significance (not supporting H5 and H8), echoing

earlier evidence that attitude alone does not reliably trigger behavioural change <sup>[25][28]</sup>.

The chained mediation results add further nuance. SN and PBC both give rise to a continuous process in which more favourable attitudes strengthen intentions, and stronger intentions subsequently raise the likelihood of green purchasing. Both sequential paths reach statistical significance (supporting H7 and H10). GCA therefore plays more of a preparatory role: although it cannot independently predict GPB, it contributes to the formation of GBI, which then converts motivation into behaviour <sup>[29][26]</sup>.

In sum, eight of the ten hypotheses are supported, indicating that the overall framework is highly consistent with the logical structure of the Theory of Planned Behaviour. The results also pinpoint Green Buying Intention as the central psychological mechanism linking attitude to behaviour. This helps explain why many university students report strong environmental attitudes yet display relatively modest behavioural engagement, and it offers concrete empirical evidence for understanding the dynamics of green consumption among young people. The full set of hypothesis results is summarised in Table 9.

*Table 9. Summary of Hypotheses Testing*

Hypothesis	Description	Supported
H1	Subjective norms have a positive effect on green consumption attitude	Yes
H2	Perceived behavioural control has a positive effect on green consumption attitude	Yes
H3	Green consumption attitude has a positive effect on green purchase intention	Yes
H4	Green purchase intention has a positive effect on green purchase behaviour	Yes
H5	Subjective norms influence green purchase behaviour through green consumption attitude	No
H6	Subjective norms influence green purchase behaviour through green purchase intention	Yes
H7	Subjective norms influence green purchase behaviour through the sequential mechanism of green consumption attitude and green purchase intention	Yes
H8	Perceived behavioural control influences green purchase behaviour through green consumption attitude	No
H9	Perceived behavioural control influences green purchase behaviour through green purchase intention	Yes
H10	Perceived behavioural control influences green purchase behaviour through the sequential mechanism of green consumption attitude and green purchase intention	Yes

## 4. Conclusions and Recommendations

### 4.1 Research Conclusions

Building on the Theory of Planned Behaviour (TPB), the analysis links two core external conditions—social expectations and perceived capability, captured by Subjective Norms (SN) and Perceived Behavioural Control (PBC)—to the internal psychological processes of Green Consumption Attitude (GCA) and Green Buying Intention (GBI), and finally to Green Purchase Behaviour (GPB). Together, these elements form an integrated framework for understanding how green purchasing develops among university students.

The empirical results show that both SN and PBC significantly reinforce students' attitudes toward green consumption. Signals from family, peers and the wider social environment, as well as students' own judgements about whether they have sufficient time, resources and ability, are all associated with more positive evaluations of green products and practices <sup>[30][14]</sup>. The findings further point to a clear progression: more favourable attitudes are associated with stronger purchasing intentions, and intention, in turn, is a powerful predictor of actual behaviour, outlining a relatively stable chain from attitude to intention and then to green purchasing <sup>[31]</sup>.

The mediation results refine this picture. SN and PBC influence GPB primarily through GBI, whereas the single mediation paths that rely only on GCA do not reach statistical significance. This pattern indicates that intention functions as the main psychological driver of green purchasing, exerting a stronger and more direct influence than attitude on its own <sup>[25][16]</sup>. At the

same time, the sequential pathway shows that SN and PBC first help to build more positive green consumption attitudes, and these enhanced attitudes then strengthen intention before behaviour takes shape <sup>[14]</sup>.

Taken together, the evidence suggests that university students' green purchasing behaviour arises from the combined effects of social influence, perceived capability, attitude formation and purchase intention. Among these, intention consistently emerges as the pivotal component linking upstream psychological factors with downstream action <sup>[25][16]</sup>. This also helps to explain why many students report strong environmental attitudes yet do not always display equally strong behavioural engagement. The findings are broadly consistent with TPB and offer a clearer account of the psychological mechanisms underlying the attitude–behaviour gap often observed in studies of green consumption <sup>[31][14]</sup>.

## 4.2 Research Recommendations

The results indicate that students' green consumption behaviour is shaped jointly by social expectations, perceived capability, attitudes and intentions. These interacting factors create multiple entry points for intervention across higher education, public policy and commercial practice <sup>[14][32][33][34][35][36]</sup>.

The empirical evidence also shows that perceived behavioural control plays a central role in shaping attitudes, intentions and actions. Universities can respond by improving access to green consumption resources, such as increasing the number of outlets selling green products, promoting second-hand exchange platforms and offering low-carbon delivery options or reusable everyday items. Reducing the time, effort and financial cost required to act in environmentally friendly ways lowers the practical threshold for participation and encourages students to view green consumption as achievable rather than aspirational <sup>[37][38][39]</sup>.

Commercial actors around university campuses reinforce or weaken these tendencies. Retailers and service providers around university campuses can also shape how far students move from intention to concrete green purchasing. When green products are easy to find, straightforward to use and perceived as reliable, students are less likely to abandon their plans at the decision stage <sup>[31][40]</sup>. Tactics such as temporary price discounts, simple loyalty programmes or deposit–refund and reusable packaging schemes can further raise the appeal of sustainable options and keep students choosing them even when money is tight <sup>[41][38]</sup>. Public policy can reinforce these efforts by building incentives for sustainable behaviour into everyday campus life <sup>[42][43]</sup>.

## 5. Research Limitations

Despite offering both theoretical and practical insights, the study still has several limitations that leave room for improvement in future work. The use of self-administered questionnaires means that the data are likely to be affected by social desirability bias, as some respondents may give answers that appear more environmentally responsible than their actual behaviour. Later studies could combine questionnaires with behavioural tracking data, field or laboratory experiments and real purchasing records, so that green purchasing behaviour is observed in a more objective and verifiable way.

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# The Theoretical Mechanism, Practical Dilemmas, and Innovative Pathways of Carbon Emission Rights Trading on the Financial Performance of “Three-High” Enterprises

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**Abstract:** Against the backdrop of increasingly severe global climate change, reducing greenhouse gas emissions has become a focal issue faced by the world collectively. The extractive industrial society, while enhancing socio-economic benefits, has also triggered a series of environmental and resource issues. “Three-High” enterprises (high pollution, high energy consumption, high emission) have become the primary entities regulated under the carbon emission rights trading system. Based on the Coase Theorem and the theory of diminishing marginal cost, this paper takes “Three-High” enterprises as the main research object and explores the financial impact of carbon emission rights trading on them from three aspects: the cost transmission mechanism, the revenue impact mechanism, and the market risk transmission mechanism. By examining the construction and implementation of carbon emission trading markets worldwide, the study investigates the main dilemmas in how carbon emission rights trading affects the financial performance of “Three-High” enterprises. The research findings indicate that the current fragmentation of the global carbon trading market mechanism makes it difficult for enterprises to formulate comprehensive financial development plans for carbon costs and carbon assets. Internally, insufficient financial management capabilities within enterprises also constrain the application of carbon emission rights. Furthermore, policy fluctuations and an imperfect external regulatory system reduce the stability of the carbon emission rights trading market, thereby creating uncertainties for corporate finances. Based on these issues, the study proposes innovative pathways for the impact of carbon emission rights trading on the financial performance of “Three-High” enterprises from three perspectives: promoting the standardization and coordinated development of the global carbon emission rights trading market; enhancing enterprises’ capabilities in managing carbon costs and carbon asset revenues; and optimizing the policy regulatory system to reduce financial uncertainties. It is hoped that this research can provide theoretical references for “Three-High” enterprises to optimize their financial performance under the carbon emission rights trading mechanism and assist them in achieving a sustainable transformation while addressing the challenges of climate change.

**Keywords:** Carbon Emission Rights Trading; “Three-High” Enterprises; Financial Performance

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## 1.Introduction

Since the beginning of the 21st century, the acceleration of industrialization has led to rising global temperatures, making carbon emissions an increasingly severe issue that has garnered worldwide attention. To address the problem of greenhouse gas emissions, the international community has successively established agreements such as the Kyoto Protocol, the Paris Agreement, and related accords. These agreements employ measures such as carbon taxes, carbon emission trading, and fiscal subsidies to regulate and reduce carbon emissions. The European Union launched the EU Emissions Trading System (EU ETS) in 2005, which became the world's first large-scale case of using market mechanisms to manage greenhouse gas emissions. The system plans to implement the Carbon Border Adjustment Mechanism (CBAM) starting in 2026, gradually phasing out free carbon emission allowances.

Carbon peak and carbon neutrality, as policy orientations that can significantly mitigate climate change, are gradually becoming a global consensus. As the world's second-largest economy and the largest carbon emitter, China solemnly announced at the global environmental governance forum in September 2020 that it would strive to peak carbon emissions before 2030 and achieve carbon neutrality before 2060. This marks the first time China has clearly communicated to the world a timeline for achieving carbon neutrality as a major energy-consuming country. Currently, to actively implement the "dual carbon" goals, China is vigorously advancing the construction of a carbon emission trading market, using market mechanisms to guide enterprises in reducing carbon emissions and promoting green, low-carbon development.

"Three-High" Enterprises refer to enterprises characterized by high pollution, high energy consumption, and high emission. These companies typically rely on intensive energy inputs and employ relatively traditional and outdated production processes, reflecting a resource-intensive development model. As a result, they contribute significantly to carbon emissions, resource depletion, and environmental pollution. In particular, typical "Three-High" industries such as steel, cement, and chemicals account for a substantial proportion of total carbon emissions.

Under the constraints of an increasingly mature carbon emission trading market and China's "dual carbon" goals (peak carbon by 2030, carbon neutrality by 2060), the development model of "Three-High" enterprises faces multiple challenges. From a policy perspective, governments continue to introduce stricter environmental regulations and carbon emission monitoring measures, imposing limits on the carbon emission allowances of such enterprises. If a company exceeds its carbon quota, it may face penalties such as heavy fines, production restrictions, or even suspension of operations. From a market perspective, the operation of the carbon emission trading market has turned carbon emissions into a factor of production with clear economic costs. If enterprises fail to control their carbon emissions effectively, they must purchase additional carbon allowances on the market, which directly increases production costs, reduces profit margins, and weakens the price competitiveness of their products. At the same time, growing consumer environmental awareness and increasing demand for green and low-carbon products mean that traditional products offered by "Three-High" enterprises may face shrinking market demand.

Therefore, an in-depth study of the impact mechanism of carbon emission trading on the financial performance of "Three-High" enterprises, an analysis of the challenges they face in practice, and the exploration of innovative development pathways are of significant practical importance. Such efforts will not only help "Three-High" enterprises better adapt to carbon trading policies and achieve financial optimization and sustainable development, but also contribute substantially to global climate governance, the realization of China's "dual carbon" goals, the establishment of a green low-carbon economic system, and the transformation and upgrading of industrial structure.

## **2. Conceptual Definition and Theoretical Mechanism of How Carbon Emission Trading Affects the Financial Performance of "Three-High" Enterprises**

### **2.1 Conceptual Definitions**

#### **2.1.1 Concept of Carbon Emission Trading**

Carbon emission rights refer to a type of entitlement that can be bought, sold, or transferred within the carbon emission trading market. In essence, this entitlement represents the legal permission granted to an enterprise to emit a certain amount of carbon dioxide and other greenhouse gases within a specific period. Under the framework of the Kyoto Protocol, carbon emission rights are recognized as a form of property right. Carbon emission trading allows participants to treat carbon

emission allowances as tradable commodities. Within this framework, trading activities encompass key steps such as the creation, allocation, buying and selling, settlement/retirement, and carrying over of carbon emission allowances.

The allocation and management of carbon emission rights are generally administered by designated national departments and authorized institutions. This process is consistently centered around the government's definition of the total carbon emission cap for a specific region, which is then allocated to various economic entities in the form of quotas. The distribution of quotas is based on the benchmarking principle and incorporates specific unit exemption mechanisms to accurately determine the amount of allowances each generating facility should receive.

### **2.1.2 The Concept of “Three-High” Enterprises**

“Three-High” enterprises refer to those whose production activities typically inflict severe damage upon the ecological environment, constituting a collective term for enterprises that generate substantial economic value at the expense of environmental depletion. During periods of capital accumulation, such enterprises frequently achieve rapid output through substantial energy consumption and environmental pollution, thereby driving swift local economic growth and even becoming pivotal pillars of regional economies. Consequently, “Three-High” characterises enterprises exhibiting high pollution, high energy consumption, and high emission in their production operations. Within the context of climate governance, these enterprises have become primary targets for environmental regulatory constraints. Building upon existing research and utilising the classification criteria for heavily polluting industries outlined in China's Guidelines for the Classification of Listed Companies by Industry (2012 Edition), this paper categorises enterprises within the following sixteen sectors as heavily polluting: thermal power generation, steel, cement, electrolytic aluminium, coal, metallurgy, chemicals, petrochemicals, building materials, papermaking, brewing, pharmaceuticals, fermentation, textiles, leather, and mining.

## **2.2 Theoretical Basis of Carbon Emission Trading Mechanisms**

The origin of carbon emission trading can be traced back to the 1960s, when American economist Dales proposed the Emissions Trading Theory, which laid an important theoretical foundation for the construction of carbon emission trading markets. The emissions trading theory posits that environmental resources are commodities with economic value, and that utilizing market mechanisms to achieve optimal allocation of resources can solve environmental pollution problems. Building on this, the Kyoto Protocol signed in 1997 became a key milestone in the development of carbon emission trading. The protocol clearly defined the emission reduction obligations of developed countries and innovatively proposed three flexible mitigation mechanisms: International Emissions Trading (IET), the Clean Development Mechanism (CDM), and Joint Implementation (JI). Among these, carbon emission trading, as one of the core mechanisms, formally entered the historical stage of global climate change response.

From a theoretical perspective, the Coase Theorem provides solid theoretical support for carbon emission trading. The Coase Theorem suggests that, under the conditions of zero transaction costs and clearly defined property rights, regardless of how initial property rights are allocated, the market mechanism can drive resources towards an optimal allocation, achieving a Pareto optimal state. In carbon emission trading, carbon emission rights are endowed with clear property attributes, becoming a commodity that can be freely traded on the market. Enterprises, considering their own emission reduction costs, trade carbon emission rights through the market, thereby minimizing the overall social cost of emission reduction. If an enterprise has low abatement costs, it can reduce emissions at a lower cost and sell its surplus carbon emission allowances to enterprises with higher abatement costs. For enterprises with high abatement costs, purchasing allowances is more economically efficient than reducing emissions themselves. Such transactions allow both parties to meet their respective emission reduction needs without incurring excessive costs, achieving efficient resource allocation.

The Marginal Abatement Cost Theory is also an important theoretical basis for carbon emission trading. Due to differences in production technology, processes, and energy structures among enterprises, their marginal abatement costs also vary. Enterprises with lower marginal abatement costs have a greater advantage in the emission reduction process, as they can achieve greater reduction volumes at relatively lower costs. Conversely, enterprises with higher marginal abatement costs face greater difficulties and higher costs in reducing emissions. The carbon emission trading market provides a platform for these

enterprises to trade with each other. This allows enterprises with lower abatement costs to convert their emission reduction achievements into economic benefits, while enterprises with higher costs can purchase carbon emission rights to meet their own emission needs, avoiding disruptions to normal production and operations caused by excessively high abatement costs. This trading mechanism, based on differences in marginal abatement costs, can fully mobilize enterprises' enthusiasm for emission reduction, improve the efficiency of total societal emission reduction, and achieve set emission reduction goals at the lowest social cost.

## **2.3 Theoretical Mechanisms of How Carbon Emission Trading Affects the Financial Performance of “Three-High” Enterprises**

The impact of carbon emission trading on the financial performance of “Three-High” enterprises is primarily realized through three theoretical mechanisms: cost transmission, revenue impact, and risk transmission.

### **2.3.1 Cost Transmission Mechanism**

Carbon emission trading affects the production and operational costs of “Three-High” enterprises, which can be categorized into direct cost increases and indirect cost increases. For Direct Costs, under a carbon emission trading system (ETS), a carbon emission allowance represents the permitted quota of carbon dioxide and other greenhouse gases that an enterprise is allowed to emit. If an enterprise's actual emissions exceed its allocated quota, it must purchase additional allowances on the market. Due to their high energy consumption and high emission characteristics, “Three-High” enterprises often have actual emissions that exceed their allocated quotas. Consequently, they face increased direct costs, such as purchasing carbon emission allowances and potentially paying carbon taxes, which significantly affect their operational costs. According to relevant research reports from the International Energy Agency (IEA), carbon prices in major global carbon markets are projected to continue rising in the coming decades, further increasing the cost burden for “Three-High” enterprises purchasing allowances. Additionally, a carbon tax, levied on corporate carbon emission behavior, aims to incentivize emission reduction through economic means. As carbon reduction policies advance, the likelihood of carbon tax implementation increases. Once a carbon tax is introduced, enterprises will face new direct cost pressures.

For Indirect Costs, indirect costs for “Three-High” enterprises under the ETS will also be affected by factors such as equipment upgrades, investments in technology research and development (R&D), and ripple effects on supply chain costs triggered by emission reduction actions. To comply with environmental monitoring requirements, “Three-High” enterprises often need to upgrade existing equipment and adopt more advanced energy-saving and emission-reduction technologies. For instance, the initial investment for equipment upgrades in a medium-scale cement plant could be as high as tens of millions of RMB, with annual maintenance and operational costs also amounting to millions. Technological R&D similarly requires substantial investment of funds and human resources. To develop more efficient emission reduction technologies, enterprises need to establish professional R&D teams and conduct long-term research and experiments. This process entails not only the risk of technical failure but also continuous capital investment for equipment procurement, material consumption, and personnel salaries, thereby driving up the indirect costs for “Three-High” enterprises.

### **2.3.2 Revenue Impact Mechanism**

Carbon emissions trading may not only increase enterprises' production and operational costs, but carbon asset revenues in the carbon trading market will also become a significant source of income for “Three-High” enterprises under the carbon emissions trading system. This is primarily achieved by optimizing carbon emissions management and selling surplus allowances or CCERs. First, enterprises can reduce actual carbon emissions by optimizing carbon emission management through energy-saving and emission-reduction measures such as improving production processes and enhancing energy efficiency. This generates surplus carbon emission allowances that can be sold on the market, generating revenue for the enterprise. Second, CCERs generated from voluntary emission reduction projects also provide enterprises with avenues to obtain carbon asset income. Enterprises generate carbon reductions by investing in renewable energy projects like solar photovoltaic or wind power generation, or by participating in forest carbon sink initiatives. These reductions, verified and converted into CCERs, are sold on the carbon emissions trading market, yielding annual returns for enterprises.

The advancement of carbon emissions trading also indirectly boosts product market revenues for “Three-High” enterprises



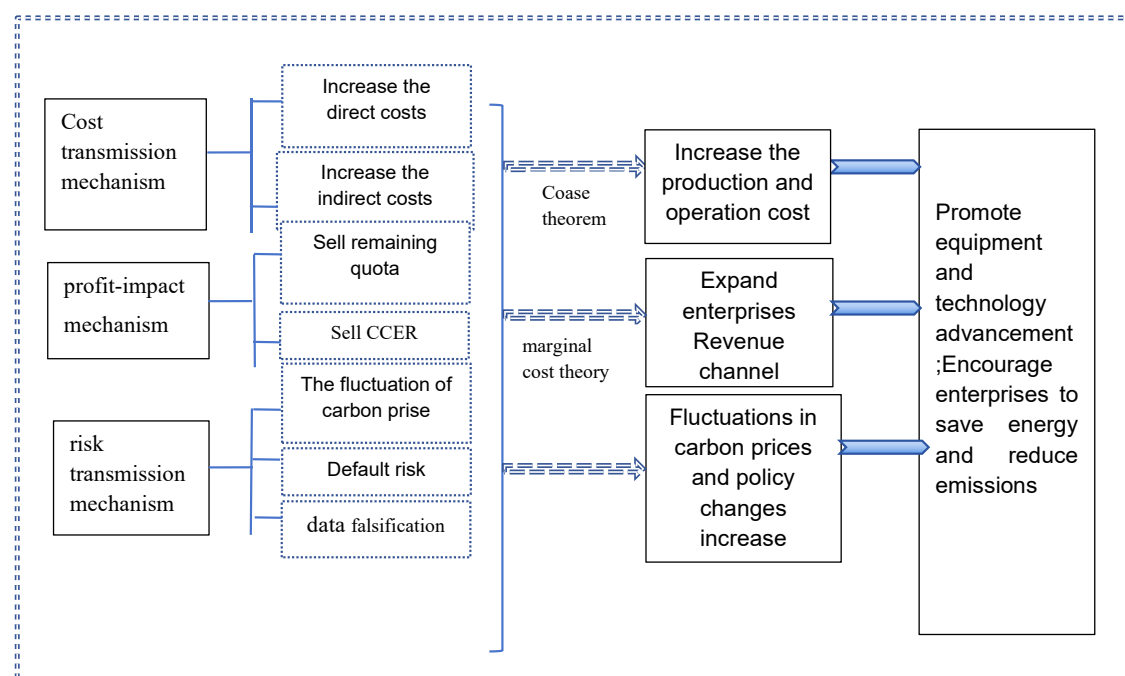
through green product premiums and expanded market share. As consumer environmental awareness grows and green consumption concepts become widespread, market demand for green, low-carbon products will intensify. If “Three-High” enterprises proactively adjust their product portfolios to manufacture green products meeting low-carbon standards, they can enhance their environmental image, thereby expanding market share and creating new profit growth points.

### 2.3.3 Risk Transmission Mechanism

Fluctuations in carbon prices and policy changes will also cause “Three-High” enterprises to face certain market risks in carbon emission rights trading, thereby affecting the financial performance of enterprises. Please provide the text you would like translated.

Fluctuations in carbon prices are one of the main manifestations of market risks. From the perspective of market supply and demand, if the supply of carbon emission quotas in the market is excessive and the supply of quotas is relatively stable, it will lead to a decline in carbon prices. Conversely, when the economy recovers and enterprises expand their production scale, the demand for carbon emissions increases. If the supply of quotas is insufficient, carbon prices will rise. With the construction and advancement of the carbon emission rights trading market, carbon trading may become an important channel for some “Three-High” enterprises to gain profits or make investments. Therefore, fluctuations in carbon prices will have an impact on the stability of enterprises’ production and operation. Policy changes also bring uncertainties to enterprises. Adjustments in the government’s carbon emission reduction policies and carbon emission rights trading rules can have a significant impact on the production and operation and financial conditions of enterprises. If the government tightens the allocation standards for carbon emission quotas, the quotas obtained by enterprises will decrease, which may force enterprises to increase their investment in emission reduction or purchase more quotas, thereby increasing costs.

Figure 1: Theoretical Transmission Mechanism of the Impact of Carbon Emission Rights Trading on the Financial Performance of “Three-High” Enterprises



In addition, in carbon emission rights trading, credit issues such as counterparty default and data fraud pose potential financial risks to “Three-High” enterprises. Counterparty default risk is an important component of credit risk. During the carbon emission rights trading process, both parties may fail to fulfill their contractual obligations for various reasons, leading to default situations. When the contract performance period is approaching, the seller may be unable to provide sufficient quotas due to poor business operations, forcing the buyer to purchase quotas at a higher price in the market to meet their own carbon emission needs. This not only increases the buyer’s procurement costs but may also result in penalties due to delayed performance, causing economic losses to the enterprise. Inaccurate credit evaluations by credit rating agencies

of counterparties also increase the default risk for enterprises. If credit rating agencies fail to fully consider the potential risk factors of counterparties and give overly high credit ratings, enterprises may suffer default losses when conducting transactions based on these ratings. Please provide the text you would like translated.

Data falsification is another serious credit issue. Some enterprises may engage in data falsification to reduce carbon emission costs or gain more economic benefits. Such behavior will undermine the fairness and transparency of the market, affect the confidence of market participants in the carbon market, cause abnormal fluctuations in carbon prices, and indirectly affect the financial conditions of other enterprises. Based on the Coase Theorem and marginal cost theory, carbon emission rights trading will influence the financial performance of “Three-High” enterprises by affecting their carbon trading costs, carbon asset returns and trading markets.

### **3.The Impact of Carbon Emissions Trading on the Financial Performance of “Three-High” Enterprises: Practical Dilemmas**

#### **3.1 Fragmentation of the Global Carbon Market Disrupts Corporate Financial Planning**

Generally, the maturity of a market mechanism provides a more favorable environment for transactions between enterprises, facilitating the achievement of a Nash equilibrium. Similarly, the maturity of carbon market mechanisms directly determines the stability of costs and revenues for “Three-High” enterprises participating in trading. Currently, the global carbon market is characterized by multiple parallel standards and fragmented operations. This decentralized, fragmented governance model has become a major obstacle for companies in managing carbon assets within their financial systems. From the perspective of carbon price formation, even in mature markets like the EU Emissions Trading System (EU ETS), significant price volatility persists. In 2024, EU allowance prices fluctuated between € 70 and € 95 per tonne, with single-day surges exceeding 15% during policy adjustment periods. For instance, a European steel company with annual emissions of 5 million tonnes could face annual carbon cost variations exceeding tens of millions of euros for every € 10/tonne price fluctuation, making it impossible to accurately predict carbon expenditure in annual financial budgets.

The instability of emerging carbon markets is even more pronounced. According to data from the China Carbon Market Information Network, the average daily trading volume in China’s national carbon market in 2023 was less than 500,000 tonnes, merely 0.05% of the EU ETS’s average daily volume. This leaves “Three-High” enterprises frequently grappling with the difficulty of selling surplus allowances or purchasing urgently needed allowances at reasonable prices. Furthermore, global liquidity mismatches and a shortage of financial instruments exacerbate financial risks. Currently, 38 mandatory carbon markets worldwide cover 23% of global greenhouse gas emissions, yet only 12% of these markets have introduced carbon derivatives. Although the EU ETS boasts the most comprehensive product suite, it only launched carbon futures in 2021. Markets like South Korea and New Zealand still lack basic hedging tools, preventing “Three-High” enterprises from effectively managing price risks. In the voluntary carbon market, the coexistence of six major standards, such as VCS and GS, leads to verification cost differences of up to 30% for the same project under different standards. Moreover, only about 60% of VCS-certified emission reductions are recognized by regional mandatory markets, severely limiting the value realization of corporate carbon assets.

#### **3.2 Inadequate Internal Carbon Financial Management Capability Constrains Cost Optimization**

Long reliant on high-carbon, high-emission production models, “Three-High” enterprises have historically paid little attention to carbon financial management, resulting in significant gaps in their systems for managing carbon emission costs and carbon asset trading. The most prominent issue is a lack of professional expertise. A 2024 International Energy Agency survey of 200 global energy and manufacturing firms revealed that approximately 68% had not established dedicated carbon asset management teams. Additionally, 45% of U.S. refineries, due to insufficient expertise, could not accurately calculate baseline emissions. This led to situations where they either over-allocated allowances, causing assets to sit idle, or under-allocated, forcing emergency purchases at high prices. This is not an isolated case; Chinese power companies face similar challenges.

Furthermore, carbon emission allowances, as a 21st-century concept, are generally not incorporated into traditional financial risk management frameworks. Data from the International Carbon Action Partnership indicates that between 2022 and 2024, 37% of European “Three-High” enterprises did not factor carbon costs into their return-on-investment calculations for new

project decisions. This resulted in newly commissioned facilities incurring losses due to rising EU carbon prices. Disclosure gaps are even more significant in emerging economies. In India, only a small fraction of large steel companies comply with the carbon disclosure requirements of the Securities and Exchange Board. In Brazil, a striking 41% of mining companies faced fines due to incomplete carbon asset reporting, with their financing costs consequently increasing by 1.8 to 2.5%. Moreover, ineffective cross-departmental coordination is a common global problem. Production departments tend to prioritize output increases, while finance departments focus on cost control. This misalignment leads to a disconnect between carbon reduction investments and financial planning.

### **3.3 Policy Volatility and an Incomplete Regulatory System Increase Financial Uncertainty**

#### **3.3.1 Fragmentation in Global Carbon Market Trading Mechanisms Disrupts Corporate Financial Planning**

Generally, the maturity of a market mechanism provides a more favorable external environment for transactions between enterprises, facilitating the achievement of a Nash equilibrium. Similarly, the maturity of a carbon market mechanism directly determines the cost and revenue stability for “Three-High” enterprises when participating in the market. Currently, the global carbon market exhibits a fragmented landscape with multiple standards operating in parallel. This compartmentalized, piecemeal management model has become a major obstacle for enterprises in managing their carbon assets. In terms of carbon price formation, even in mature markets like the EU Emissions Trading System (EU ETS), significant price volatility persists. In 2024, EU Allowance (EUA) prices fluctuated between € 70 and € 95 per ton, with single-day surges exceeding 15% during policy adjustment periods. For example, a European steel company with an annual emission of 5 million tons could see a difference in its annual carbon cost exceeding tens of millions of euros for every € 10/ton fluctuation in the carbon price. This volatility makes it impossible for companies to accurately forecast their carbon expenditure in annual financial budgets.

Instability is even more pronounced in emerging emissions trading schemes. According to data disclosed by China Carbon Market Information Network, the average daily trading volume in China’s national carbon market in 2023 was less than 500,000 tons, a mere 0.05% of the EU ETS’s average daily volume. This situation frequently leaves “Three-High” enterprises struggling to sell surplus allowances or purchase needed allowances at reasonable prices. Furthermore, global liquidity mismatches and a shortage of financial instruments exacerbate financial risks. Currently, 38 mandatory carbon markets worldwide cover about 23% of global greenhouse gas emissions, but only 12% of these markets have launched carbon derivatives. Although the EU ETS boasts the most complete product suite, it only launched carbon futures in 2021. Markets like South Korea and New Zealand still lack basic hedging tools, preventing “Three-High” enterprises from effectively managing price risks. In the voluntary carbon market, six major standards like VCS and Gold Standard coexist. Verification costs for the same project can differ by up to 30% across these standards, and only about 60% of Voluntary Carbon Units (VCUs) issued under VCS are recognized by regional compliance markets, severely restricting the value realization of corporate carbon assets.

#### **3.3.2 Insufficient Internal Carbon Financial Management Capability Hinders Corporate Cost Optimization**

“Three-High” enterprises, long reliant on high-carbon, high-emission production models, have historically neglected carbon financial management, resulting in significant shortcomings in their systems for managing carbon emission costs and carbon asset trading. The most prominent issue is a lack of specialized expertise. A 2024 International Energy Agency (IEA) survey of 200 global energy and manufacturing companies revealed that approximately 68% had not established dedicated carbon asset management teams. Due to insufficient expertise, 45% of U.S. refineries could not accurately calculate their baseline emissions, leading either to over-allocation of allowances (causing idle assets) or under-allocation (forcing emergency purchases at high prices). This is not an isolated case; Chinese power companies face similar challenges.

Moreover, carbon emission allowances, as a 21st-century concept, are generally not incorporated into traditional financial risk frameworks. Data from the International Carbon Action Partnership (ICAP) indicates that between 2022 and 2024, 37% of European “Three-High” enterprises did not factor carbon costs into their Return on Investment (ROI) calculations for new project investment decisions. This oversight resulted in newly operational facilities incurring losses due to rising EU carbon prices. The disclosure gap is more significant in emerging economies. In India, only a small portion of large-scale steel

companies meet the carbon disclosure requirements of the Securities and Exchange Board of India (SEBI). In Brazil, as many as 41% of mining companies faced penalties due to incomplete carbon asset reporting, subsequently seeing their financing costs increase by 1.8% to 2.5%. Additionally, failed cross-departmental coordination is a common global issue. Production departments often prioritize output increases, while finance departments focus more on cost control. This misalignment leads to a disconnect between carbon reduction investments and financial planning.

### **3.3.3 Policy Volatility and an Incomplete Regulatory System Increase Financial Uncertainty**

A volatile policy environment and uneven regulatory enforcement globally impose additional financial burdens on “Three-High” enterprises. Policy fragmentation and unpredictability have become major risks for these companies in the carbon market. Currently, the EU simultaneously implements the Emissions Trading System and regulations on the carbon intensity of maritime fuels. This dual regulation has significantly increased compliance costs for shipping companies, with an estimated 30% of these costs attributed to unclear policy coordination.

Beyond market fluctuations induced by policy, significant gaps also exist between regions in their Monitoring, Reporting, and Verification (MRV) systems. The EU achieves a data accuracy rate of about 98% through unified satellite monitoring, while Southeast Asia still relies heavily on manual reporting, resulting in larger measurement deviations. In a case investigated by the IEA, a Malaysian chemical company in 2023 faced a discrepancy of 1.2 million tons in its calculated emissions due to differences in accounting methodologies used by different verification bodies. Such disparities in emissions accounting, stemming from policy and statistical caliber differences, pose substantial risks to corporate development. Furthermore, penalties for global carbon data fraud show signs of local protectionism. Sanctions for corporate carbon data falsification vary significantly across regions, with low violation costs in some areas. This unfair implicit protection effectively condones data fraud.

## **4. Innovative Pathways for Emissions Trading to Influence the Financial Performance of “Three-High” Enterprises: Mitigation Strategies**

Addressing the practical challenges outlined above regarding how emissions trading affects the financial performance of “Three-High” enterprises, this paper proposes targeted countermeasures from three dimensions: international coordination, enterprise self-improvement, and policy regulation.

### **4.1 Promoting the Standardization and Coordinated Development of the Global Carbon Emissions Trading Market**

To mitigate the disruptions that parallel standards and operational fragmentation in the global carbon market cause to corporate financial planning, international rule-making bodies should take the lead. Under the framework of the United Nations Framework Convention on Climate Change (UNFCCC) and in collaboration with institutions like the World Bank and the International Energy Agency (IEA), efforts should be made to establish globally unified standards for carbon allowance accounting and a mutual recognition mechanism for certified emission reductions. This would reduce regulatory discrepancies between different markets. By gradually achieving mutual recognition of emission reductions between voluntary carbon standards (e.g., VCS, Gold Standard) and compliance markets (e.g., EU ETS, China’s national ETS), verification costs for cross-market transactions can be lowered, and accounting differences arising from disparate standards can be minimized (Li & Lai, 2025).

Regarding inter-market linkages, mature carbon markets can foster the development of emerging markets through “linking mechanisms.” The EU could expand the scope of its linkage with the UK and Swiss carbon markets. China could promote pilot programs for coordination between its national ETS and regional markets like the Guangdong-Hong Kong-Macao Greater Bay Area, enhancing market liquidity through mutual allowance recognition and joint trading platforms. Simultaneously, countries should be encouraged to accelerate the development of carbon derivative markets. Drawing on the EU’s experience with carbon futures, markets like South Korea and New Zealand should gradually introduce tools such as carbon futures and options. This would provide “Three-High” enterprises with means to hedge against carbon price volatility, preventing financial risks associated with a lack of risk management instruments.

### **4.2 Enhancing Enterprise Capability in Managing Carbon Emission Costs and Carbon Asset Returns**

“Three-High” enterprises are often capital-intensive, leading their financial management teams to focus expertise traditionally on areas like fixed asset management and cost-budget control. Emissions trading and the associated management of related revenues and costs, as novel domains, impose higher competency requirements on corporate financial personnel. Therefore, in the context of emissions trading, “Three-High” enterprises should invest in specialized training to upgrade their financial staff’s knowledge in new areas such as carbon market rules, carbon financial accounting, and environmental science. By combining internal training with external recruitment, the professionalism of the finance department can be enhanced, and the enterprise’s capacity for carbon emission and carbon asset accounting can be strengthened. This lays the foundation for effective management of carbon costs and carbon asset returns.

Regarding the refinement of financial systems, it is essential to fully integrate carbon factors into traditional financial management processes. A separate “Carbon Cost Budget” line item should be established during budget formulation, incorporating carbon price forecasts to predict annual carbon expenditures. In investment decision-making, carbon costs must be included in project Return on Investment (ROI) calculations. European “Three-High” enterprises can reference long-term EU carbon price trends to assess the profitability feasibility of high-carbon projects, thereby avoiding losses in newly operational facilities due to carbon price increases. Furthermore, enterprises must strictly comply with local disclosure requirements to improve carbon asset information reporting, reducing the risks of penalties and increased financing costs due to incomplete reporting.

To improve internal departmental coordination, regular carbon management meetings should be convened to establish a linkage mechanism among production, finance, and environmental protection departments. The production department needs to provide timely feedback on how production plan adjustments affect carbon emissions. The finance department can then optimize carbon cost control strategies accordingly, supported by emission monitoring data from the environmental protection department. This helps prevent misalignment between carbon reduction investments and financial planning caused by departmental silos.

### **4.3 Optimizing the Policy and Regulatory System to Reduce Financial Uncertainty**

Addressing the primary issue of inadequate regulation in current emissions trading, organizations like the International Carbon Action Partnership (ICAP), the UNFCCC, and the IEA should actively promote the unification and standardization of emissions trading, working towards a harmonized global system for Monitoring, Reporting, and Verification (MRV). Climate governance and the execution of “dual carbon” goals cannot be achieved by any single country alone. Leveraging the EU’s advanced satellite monitoring technology, the EU should provide corresponding technical support to emerging emissions trading markets in regions like Southeast Asia and Africa. By sharing experience and facilitating technology transfer, these relatively underdeveloped regions can gradually transition from manual reporting to automated monitoring, thereby minimizing regional measurement deviations.

Furthermore, concerning market incoordination and the issue of overlapping carbon tax levies, synergistic design between carbon taxes and carbon markets should be strengthened. In cross-border carbon transactions between different countries and regions, clear deduction ratios between carbon taxes and carbon allowances should be established to prevent increased corporate carbon costs due to double taxation. Regarding enforcement, the penalty costs for carbon emission data fraud must be substantially increased. Simultaneously, local protectionism should be rejected, and cross-regional supervision should be implemented to address lax enforcement in certain jurisdictions. This ensures a fair competitive environment for compliant enterprises and avoids carbon cost disparities stemming from regulatory differences.

## **5. Conclusion**

Against the backdrop of the continuous development of international carbon emissions trading, nations are increasingly prioritizing the implementation of emissions trading pilots. Based on the aforementioned research, this paper argues that by promoting the standardization and coordinated development of the global carbon emissions trading market, the current fragmented market landscape can be broken. This would lower the costs and risks for enterprises engaging in cross-market transactions, creating a stable and predictable operating environment for carbon asset management. On the other hand, by enhancing their internal capabilities in managing carbon emission costs and carbon asset returns, and by fully



integrating carbon factors into all aspects of financial management—from building professional expertise to optimizing inter-departmental coordination mechanisms—enterprises can effectively improve their competitiveness within the carbon market, achieving cost optimization and profit maximization. In the future, as carbon emissions trading mechanisms continue to improve and mature, “Three-High” enterprises must consistently monitor market dynamics and policy changes, flexibly adjust their financial strategies, and enhance their capabilities in managing financial carbon costs and carbon assets. Only by doing so can they better adapt to the evolving demands of the carbon market, achieving a win-win outcome for both economic efficiency and environmental benefits.

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# Compatibility Dilemmas and Optimization Paths of Patient Capital Empowering Green Industries Under the Dual Carbon Goals

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**Abstract:** This study aims to explore how patient capital can facilitate the development of green industries in the context of the “dual carbon” goals, while analyzing the problems existing in their cooperation and proposing solutions. Combining the development needs of green industries with the characteristics of patient capital, this research systematically examines the unique roles of patient capital in three dimensions—time adaptation, risk bearing, and value alignment—through sorting out relevant theories and practical cases. The results indicate that the effective connection between patient capital and green industries currently faces practical obstacles such as insufficient capital scale, information opacity, narrow exit channels, and fragmented policy support. Based on this, the study proposes optimization paths including expanding the sources of patient capital, establishing information sharing platforms, improving supporting mechanisms, and strengthening policy guarantees. The research shows that the in-depth integration of patient capital and green industries can provide important support for the achievement of the “dual carbon” goals. The relevant conclusions can offer practical references for promoting the high-quality development of green industries and enhancing the synergy between capital and industries.

**Keywords:** Dual Carbon Goals; Patient Capital; Green Industries; Compatibility Dilemmas; Optimization Paths

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## 1.Introduction

As China’s core strategy to address global climate change and promote systemic economic and social transformation, the “dual carbon” goals are not only significant in terms of ecological value—such as reducing carbon emissions and improving the ecological environment—but also in forcing the green transformation of industrial structures, stimulating the vitality of green technological innovation, and building a modern industrial system characterized by low energy consumption, high output, and sustainability. They provide important scenarios and driving forces for nurturing new quality productive forces, while offering Chinese solutions and contributions to global climate governance. As the core carrier for achieving the “dual carbon” goals, the development of green industries urgently requires technological innovation breakthroughs to overcome green and low-carbon technological bottlenecks, diversified capital empowerment to meet long-term investment needs, improved institutional systems to optimize the market development environment, and cross-subject collaboration to form an ecological development pattern, ultimately realizing the organic unity of economic, ecological, and social benefits.

Patient capital, characterized by long-term orientation, risk tolerance, and ecological empowerment, shares an in-depth alignment logic with the development of green industries:

In the time dimension, its long-term investment attribute matches the slow-return characteristics of green technology R&D and green project construction, effectively resolving the maturity mismatch between short-term capital and the long industrial cycle. In the risk dimension, its risk tolerance can cover the high uncertainty of green innovation, providing stable capital support for disruptive green technological breakthroughs. In the value dimension, its orientation of balancing economic and social benefits is highly consistent with the ecological value pursuit of green industries. Through resource integration and cross-subject collaboration, it promotes the formation of a positive feedback loop of “capital-technology-industry” in green industries, becoming a key capital form to address the financing constraints of green industries and activate green innovation momentum.

## **2.The Unique Value of Patient Capital to Green Industries**

### **2.1 Matching the Long-Cycle Development Law of Green Industries**

#### **2.1.1 Aligning with the Iteration Cycle of Green Technology R&D**

Core technological innovations in green industries—such as the R&D of new green and low-carbon building materials, breakthroughs in clean coal utilization technology, and advancements in carbon capture, utilization, and storage (CCUS) technology—require a long process of repeated experimentation and optimization, with difficulty in achieving commercial returns in the short term. Patient capital breaks away from the traditional capital’s pursuit of short-term gains, supporting technologies from laboratory research to industrial application from a long-term investment perspective, and avoiding R&D interruptions due to funding shortages (Yang, 2025). For example, in the field of nearly zero-energy consumption buildings, the R&D of energy storage technology and low-carbon materials requires continuous investment, and the long-term empowerment of patient capital can ensure the continuity of technological iteration (Yan, 2025).

#### **2.1.2 Adapting to the Value Release Cycle of Green Projects**

Green industry projects, such as forest carbon sink projects and mine ecological restoration projects, exhibit significant lag in environmental and economic value realization, requiring long-term operation to convert ecological value into economic value. By reconstructing the “time logic” of capital value appreciation, patient capital provides continuous funding supply for projects across the start-up and growth stages, matching the full-cycle needs from investment to output (Lan et al., 2025). For instance, seedling cultivation and afforestation projects in forestry require several years or even decades to form stable carbon sink capacity, and the long-term investment of patient capital can ensure the steady progress of such projects (Wang et al., 2025).

#### **2.1.3 Supporting the Continuous Upgrade Cycle of Green Industries**

The transformation and upgrading of green industries cannot be achieved overnight; it involves multiple stages such as traditional technology substitution, industrial chain restructuring, and market awareness cultivation. Patient capital can provide capital support throughout the entire industrial life cycle, helping industries develop from low-end to high-end and from fragmented to clustered, adapting to the long-term process of industrial upgrading (Chen et al., 2025). In the green and low-carbon transformation of the coal industry, the shift from high-carbon mining to clean utilization requires long-term financial guarantees, and patient capital can effectively resolve the maturity mismatch problem during the transformation process (Wang et al., 2025).

## **2.2 Bearing the High-Uncertainty Costs of Green Industries**

### **2.2.1 Tolerating the High Failure Risk of Green Technology Innovation**

Disruptive green innovation is characterized by high investment and high failure rates, as new green technologies face numerous unknown obstacles in the industrialization process. With its risk tolerance, patient capital has a higher acceptance of technological innovation failures and is willing to bear the trial-and-error costs during R&D (Zhang et al., 2025). Unlike traditional capital that pursues short-term returns and avoids high risks, patient capital can provide a “fault-tolerant space” for green technology innovation, promoting the realization of disruptive green breakthroughs (Zhuang, 2025).

### **2.2.2 Resisting Green Market Volatility Risks**

In the early stages, green products face problems such as high incremental costs, insufficient market awareness, and unstable demand, leading to significant uncertainty in market expansion. Through resource integration and ecological empowerment, patient capital helps green industry enterprises optimize resource allocation, expand market channels, and alleviate operational pressure caused by market volatility (Meng, 2025). Meanwhile, the long-term holding strategy of patient capital can reduce the impact of short-term market fluctuations on enterprise operations, ensuring stable business operations (Wang et al., 2025).

### **2.2.3 Hedging Potential Risks of Policy Adjustments**

Under the “dual carbon” goals, policies related to green industries may undergo dynamic adjustments, bringing policy uncertainty risks to industrial development. By constructing a cross-cycle investment framework, patient capital dynamically adjusts investment strategies in line with policy orientations, helping enterprises hedge against the impact of policy fluctuations (Yang, 2025). In addition, patient capital can promote enterprises to strengthen collaboration with governments and research institutions, enhancing their ability to predict and adapt to policy changes (Sun, 2025).

## **2.3 Anchoring the Symbiosis of Green Industries and Economic Value**

### **2.3.1 Balancing Economic Benefits and Ecological Efficiency**

The core goal of green industries is to achieve the coordinated win-win of economic and ecological benefits, which is highly consistent with the characteristics of patient capital—“slow work yields fine products”—and its focus on long-term returns and social benefits (Meng, 2025). Traditional capital often focuses on short-term economic returns, which may lead industries into the misunderstanding of “prioritizing economy over ecology.” In contrast, patient capital not only pursues long-term stable investment returns but also values ecological benefits such as energy conservation, emission reduction, and carbon sink enhancement, promoting green industries to achieve the dual goals of “economic value-added and ecological optimization” (Lan et al., 2025). For example, in the green transformation of the coal industry, patient capital supports enterprises in improving the economic benefits of clean production while helping them reduce carbon emissions and improve the ecological environment (Wang et al., 2025).

### **2.3.2 Aligning with Industrial Development Demands Under the “Dual Carbon” Goals**

Green industries are the core support for achieving the “dual carbon” goals, and their development demands form a strategic resonance with the long-term value orientation of patient capital. By promoting the positive feedback loop of capital-technology-industry, patient capital helps green industries overcome technological bottlenecks, expand industrial scale, and provide industrial support for the realization of the “dual carbon” goals (Yang, 2025). Meanwhile, patient capital guides social capital to flow into green fields, promoting the clustered development of green industries, forming economies of scale, and accelerating the implementation of the “dual carbon” goals (Lin et al., 2025).

### **2.3.3 Facilitating Sustainable Development with Symbiotic Multiple Values**

The development of green industries supported by patient capital can not only achieve economic and ecological values but also drive social benefits such as green employment and regional coordinated development, forming a pattern of symbiotic multiple values (Zhuang, 2025). For example, in the development of green industries in western China, patient capital can promote the integration of ecological restoration and green industries, achieving both ecological protection and regional economic development and employment growth, which is consistent with the core goal of sustainable development of green industries (Yang, 2025). This alignment of multiple values makes patient capital an important capital support for green industries to achieve the coordinated development of economy, ecology, and society.

## **3. Connection Obstacles Between Patient Capital and Green Industries**

### **3.1 Insufficient Total Amount and Single Source of Patient Capital on the Capital Side**

Currently, there is a significant gap in the supply scale of patient capital supporting the development of green industries, making it difficult to match the long-term and high-investment capital needs of green projects. Green projects such as nearly zero-energy consumption buildings, green coal transformation, and forest carbon sinks all require continuous injection of long-term capital to support technological R&D, project implementation, and industrial upgrading. However, the total amount of existing patient capital is limited, making it impossible to cover the capital needs of the entire industrial chain. In terms of

capital sources, China's patient capital mainly relies on a small number of financial institutions and government-guided funds, with insufficient participation of market-oriented capital. The financing channels are relatively single, lacking diversified long-term capital supply entities. This single-source structure not only restricts the expansion of total capital but also leads to insufficient flexibility in capital allocation, failing to accurately match the differentiated capital needs of different types of green projects, further exacerbating the financing constraints of green industries.

### **3.2 Information Opacity and Difficult Profit Judgment of Green Projects on the Industrial Side**

Green industry projects generally suffer from insufficient and non-standard information disclosure, resulting in severe information asymmetry between patient capital and project parties. In green projects such as nearly zero-energy consumption buildings and mine ecological restoration, core information such as carbon emission assessments, energy consumption reduction effects, and ecological benefit conversion lacks unified disclosure standards and verification mechanisms, making it difficult for patient capital to fully grasp the true operational status and environmental benefits of projects. Meanwhile, the returns of green projects are characterized by significant long-term nature and uncertainty, with their economic returns relying not only on market operations but also on external factors such as carbon trading and policy subsidies. Currently, there is a lack of a scientific and unified value evaluation system for green projects, making it difficult to accurately measure the long-term returns of projects. In addition, the commercial prospects of some green technologies are unclear, further increasing the difficulty for patient capital to judge project returns and inhibiting capital investment willingness.

### **3.3 Narrow Capital Exit Channels and Incomplete Incentive and Constraint Mechanisms on the Institutional Side**

The sustainable circulation of patient capital relies on a sound exit mechanism, but the current capital exit channels in the green industry field are relatively narrow, failing to meet the liquidity needs of patient capital. China's multi-level capital market has insufficient adaptability to green projects, and exit tools such as green asset securitization and carbon neutrality funds are still underdeveloped. Traditional channels such as equity exit and mergers and acquisitions have limited application scenarios in green industries. Meanwhile, the imperfection of incentive and constraint mechanisms further hinders the effective connection between capital and industries. On the incentive side, policies such as tax incentives and risk compensation for patient capital investing in green projects are insufficient, making it difficult to effectively hedge the long-term risks of projects. On the constraint side, there is a lack of regulatory measures for short-term capital behaviors, and the environmental liability accountability mechanism for green projects is not sound, leading some capital to pursue short-term returns and be unwilling to participate in long-term green investments.

### **3.4 Fragmented Policy Support and Flaws in Risk Sharing Mechanisms on the Environmental Side**

The current policies supporting patient capital to empower green industries are fragmented, lacking systematicness and synergy. Policies such as green finance subsidies and project support issued by various regions and departments have overlapping and inconsistent implementation standards, making it difficult to form policy synergy. For example, in fields such as prefabricated buildings and forest carbon sinks, the policy support intensity and subsidy methods vary greatly across regions, leading to policy uncertainty for patient capital in cross-regional allocation. Meanwhile, the risk sharing mechanism has obvious flaws, with green industry projects facing a lack of effective diversification channels for risks such as technological R&D risks, policy change risks, and market volatility risks. Existing risk sharing tools have limited coverage, and mechanisms such as government guarantees and insurance protection provide insufficient support for green projects. A multi-stakeholder risk governance system involving "government-market-enterprise" has not been formed, making patient capital "dare not invest" in green projects with high uncertainty.

## **4. Solutions**

### **4.1 Expand the Scale of Patient Capital and Attract Long-Term Capital Investment**

On the one hand, expand the total amount of patient capital through policy guidance, encourage long-term capital such as government industrial funds, social security funds, and insurance funds to enter the green industry field, give play to the leverage role of government funds, and stimulate social capital to participate in green project investment. For example, establish a national-level green patient capital guidance fund to provide equity investment and interest subsidy support for

key green industry projects. On the other hand, expand diversified financing channels, improve the green financial market system, develop financial products such as green bonds and carbon neutrality ETFs, support qualified green enterprises to list for financing, and attract market-oriented patient capital participation. Meanwhile, optimize the capital structure, promote the strategic binding of patient capital and green industries, and realize the win-win of long-term capital appreciation and industrial green transformation through the “capital + resources” cooperation model.

## **4.2 Build Information Bridges and Clarify Green Project Standards**

Establish a unified information disclosure platform and standard system for green projects, and compulsorily require green projects to disclose core information such as environmental benefits, technological maturity, and fund use plans to improve project transparency. Build a green project database and evaluation system based on digital technology, integrating carbon emission data, energy consumption data, and return forecasts to provide accurate decision-making references for patient capital. Meanwhile, improve the green project value evaluation framework, incorporate carbon sink benefits and environmental externalities into the evaluation system, and formulate scientific return calculation methods and risk assessment indicators. Encourage third-party institutions to participate in the verification and rating of green projects, issue authoritative evaluation reports, reduce information asymmetry between capital and industries, and lower the difficulty for capital to judge project returns.

## **4.3 Improve Supporting Mechanisms and Explore Green Asset Conversion**

Improve the patient capital exit mechanism and enrich exit channels and tools. Promote the development of green asset securitization, support green projects with stable cash flows such as nearly zero-energy consumption buildings and photovoltaic power plants to carry out asset securitization financing, providing liquidity outlets for patient capital. Cultivate the green industry M&A market, encourage leading enterprises to integrate high-quality green projects through mergers and acquisitions, providing exit paths for early-stage investment capital. Meanwhile, explore green asset conversion paths, establish a mechanism linking carbon trading with green project returns, and promote the conversion of environmental benefits such as forest carbon sinks and industrial emission reductions into tradable assets. Improve the full-chain collaborative mechanism of “fundraising-investment-management-exit,” enhance the operational efficiency of patient capital in green project investment, and ensure the orderly exit and recycling of capital.

## **4.4 Strengthen Policy Guarantees and Introduce Risk Compensation Measures**

Construct a systematic policy support system, integrate fragmented green industry support policies, formulate cross-regional and cross-departmental collaborative policy plans, clarify the key areas, standards, and processes of policy support, and improve policy stability and predictability. Increase policy incentives for patient capital, implement policies such as tax reductions and stamp duty exemptions for investing in green projects, and provide financial subsidies for capital holding green project equity for a long time. Meanwhile, improve the risk sharing mechanism, establish a green project risk compensation fund, and compensate a certain proportion of losses incurred by patient capital investing in green projects. Promote insurance institutions to develop exclusive insurance products for green projects, covering risks such as technological R&D and policy changes. Build a multi-stakeholder risk sharing model of “government guarantee + commercial insurance + enterprise joint guarantee,” reduce the investment risks of patient capital, and enhance their confidence in investing in green industries.

## **5. Conclusion**

This study systematically reveals the in-depth alignment logic and practical connection obstacles between patient capital and green industries under the “dual carbon” goals. The core findings indicate that patient capital, with its long-term orientation, risk tolerance, and pursuit of multiple values, can effectively adapt to the long-term needs of green industry technology R&D, project operation, and industrial upgrading. By constructing a positive feedback loop of “capital-technology-industry,” it overcomes industrial development bottlenecks. However, insufficient capital scale, information asymmetry, narrow exit channels, and fragmented policies constitute the four core obstacles to their connection. The research framework of “value alignment-obstacle analysis-path optimization” not only enriches the theoretical system in the interdisciplinary field of green finance and industrial transformation but also provides a clear plan for solving the problems of patient capital being “unwilling to invest,” “daring not to invest,” and “unable to invest” in practice. It is of great significance for promoting the synergy



between the capital market and green industries and facilitating the achievement of the “dual carbon” goals. Meanwhile, this study has limitations such as focusing on macro mechanisms, lacking discussions on segmented fields, and insufficient quantitative verification. Future research can be deepened in directions such as the differentiated adaptation needs of different green industries, the empirical measurement of the empowerment effect of patient capital, and the reference of international green capital development experience. This research also provides key implications for policy formulation: relevant departments need to expand the scale of patient capital by establishing guidance funds, improving tax incentives and risk compensation policies, establish a unified green project information disclosure and value evaluation system, smooth capital exit channels, strengthen cross-departmental policy synergy, and build a multi-stakeholder risk sharing mechanism. Through systematic measures, the efficient connection between patient capital and green industries can be promoted,

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# The Li-Xiong Queuing Framework: Dynamic Reliability Optimization for Multi-Tier Border Control Systems

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**Abstract:** As the volume of passengers passing through border checkpoints continues to increase at this stage, the traditional M/M/c model has shown certain limitations in both capacity and accuracy within port scenarios. To address this issue, Li Zhe and Xiong Wenze (the authors of this paper) developed a Multi-level Dynamic Reliability Queuing Model, also referred to as the Li-Xiong Model (MDRQM). This model enhances prediction accuracy through three core improvements: the implementation of a phased passenger flow guidance mechanism, real-time optimization of resource allocation, and the incorporation of equipment operational status correction parameters. The proposed model introduces a tiered service intensity factor and a nonlinear degradation response function, which together form a comprehensive mathematical framework and establish a new analytical structure. Field validation at the Zhuhai Port demonstrated that the new model reduces the prediction error of waiting times from 32.1% (using traditional methods) to 11.4%, thereby providing more accurate decision-making support for passenger flow management during peak periods.

**Keywords:** Li-Xiong Model; Dynamic Queuing Model; Border Control Optimization; Equipment Reliability Degradation; Resource Allocation

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## 1.Introduction

### 1.1 Research Background

As one of China's busiest passenger clearance ports, Zhuhai Port handles over 380,000 daily border crossings. The existing inspection systems now face dual pressures: Traditional manual verification methods have hit efficiency plateaus, while aging infrastructure shows growing operational deficiencies after years of use. More critically, most current theoretical studies rely on fixed-parameter models that struggle to address combined impacts, holiday passenger flow fluctuations and sudden equipment failures during peak hours.

### 1.2 Theoretical Gap

Current methods have three key issues. First, they don't factor in the ongoing drop in processing efficiency caused by equipment malfunctions, nor do they build in special lanes or priority access for emergency situations within their layered passenger flow management systems. Second, the ways we calculate and adjust resources dynamically still need work—they're not as refined as they could be. Take traditional models for example: they often miss the mark when it comes to measuring the total, compounding effect of sudden security equipment failures on the entire system's efficiency.

### 1.3 Research Contributions

- 1) A dynamic reliability correction function  $\beta(\alpha)$  is proposed.
- 2) A mathematical framework for tiered service intensity factors  $\gamma_i$  is constructed.
- 3) An intelligent algorithm prototype tailored to port operations is developed.
- 4) A nonlinear degradation function is defined, which breaks through the traditional binary-state assumption and accurately characterizes the continuous decay of service rates.

In the study of large-scale passenger service processes, queueing theory has consistently served as a primary analytical tool for scholars to assess system efficiency and service levels.<sup>[1]</sup> Since the early development of the M/M/c model by Erlang<sup>[2]</sup> for telephone exchange systems, scholars have successively proposed various queueing models—such as M/G/1, G/G/1, and M/M/1—to characterize system performance under different arrival processes, service mechanisms, and queue disciplines.<sup>[3–4]</sup> With further academic inquiry, these models have been progressively extended and applied across diverse domains including airports, banking services, transportation hubs, healthcare facilities, and large-scale event venues.<sup>[5–8]</sup>

When it comes to airports and border checkpoints, classic queueing models often assume service capacity stays steady over set periods. But that's a simplification—real-world chaos like equipment breaking down, lopsided resource distribution, or sudden surges/drops in passenger numbers can throw off service speeds in ways these models don't fully capture.

To fix this gap, some researchers have dug into how smaller details matter: think corridor layouts (how far gates are from check-in), queue lengths, or even passenger traits (age, gender, whether they're hauling heavy luggage). The idea? To better map why people choose certain security lanes, and how all these factors nudge those decisions.<sup>[9]</sup> Others have taken a different tack, rethinking how to categorize and weigh elements that shape queueing systems entirely.<sup>[10]</sup>

For example, one study built a basic tool to map how airports might assign gates, check-in desks, or baggage carousels to specific flights. They also used simulations to show real-time passenger flow in terminals, plus how non-dedicated spaces—like immigration lines, shops, or lounges—get used. Still, most of these models hold onto fixed parameters, and they don't fully grapple with reliability issues like equipment aging or failure rates that shift hour to hour.

In reliability research, lots of studies use Markov or semi-Markov processes to model how equipment flips between "working" and "failed" states. This helps track shifts in service capacity over time more precisely.<sup>[11–12]</sup> Some researchers have pointed out that tossing "failure rate functions" and "repair rate functions" into queueing models lets you tweak service efficiency in real time. That makes it easier to map how available equipment actually performs in messy, real-world setups.<sup>[13]</sup> More recent work has blended reliability ideas with predictive maintenance. By using real-time monitoring and big data tools, they can check the health of key equipment. This method helps plan maintenance early—or switch to backup systems—before a breakdown becomes likely.<sup>[14–15]</sup>

Meanwhile, a body of research has also explored the transplantation and application of multi-tiered queueing architectures in other domains. For instance, in hospital emergency departments, the implementation of priority channels for critical patients—informed by multi-level queueing principles—coupled with the integration of equipment reliability monitoring, has been shown to effectively mitigate emergency congestion and prevent patient flow disruptions caused by sudden failures of key medical equipment (e.g., CT scanners, MRI machines).<sup>[16–17]</sup> In logistics warehousing and sorting centers, priority-based balanced scheduling algorithms can dynamically adjust resource allocation for updates and queries according to user demands. Such approaches enable rational utilization of system resources, ensure preferential processing of high-priority tasks, reduce response times for critical queries, and enhance the timeliness of essential data.<sup>[18]</sup> These findings further demonstrate that multi-level dynamic reliability queueing models exhibit considerable generality and potential in service environments characterized by high load demands and stringent reliability requirements.

In the context of transportation hubs and port clearance operations, models that merely incorporate a binary-state assumption—i.e., "equipment operational" or "equipment failed"—are inadequate in capturing the gradual degradation of service capacity caused by intermediate states such as incipient faults, minor malfunctions, and severe failures. Similar research efforts include,<sup>[19]</sup> which investigates the complexity of multi-state systems operating in complex environments and undergoing degradation processes, and which addresses the challenge of determining which maintenance activities to perform

within a limited time frame in a parallel system where both individual components and the overall system may exhibit multiple potential states.<sup>[20]</sup>

In summary, at the intersection of the three dimensions—multi-tiered, dynamic, and reliability-aware—queuing theory is progressively evolving toward greater refinement and practical applicability. By embedding reliability analysis into queuing systems, it becomes possible to not only capture the continuous impact of equipment failures on service efficiency but also to provide quantitative decision support for resource scheduling during peak periods and emergency management in fault scenarios. Although existing literature has extensively validated such approaches in settings such as airports and hospitals, there remains considerable room for advancement in areas such as uncovering failure degradation mechanisms in border port contexts, performing cross-system data linkage analysis, and developing globally optimized multi-objective scheduling algorithms. Therefore, research and practice based on multi-level dynamic reliability queuing models will continue to offer theoretical guidance and practical support for multiple critical sectors—including border inspection, medical emergency services, and logistics sorting.

## 2.Theoretical Derivation of Model Construction

### 2.1 Fundamental Definitions

Passenger Classification: Green Wave(High-frequency travelers), Yellow Wave(Regular travelers), Red Wave(High-risk travelers).

$\lambda_i$  : Arrival rate of type-i passengers.

$c_i$  : Dynamic number of servers.

$\mu_0^i$  : Nominal service rate.

$\alpha$  : Equipment failure rate.

$\beta(\alpha)$  : Service degradation function.

$\gamma_i$  : Tiered service intensity factor.

### 2.2 Derivation of Core Formula

#### 2.2.1 Effective Service Rate Model

Accounts for the continuous impact of equipment failure on service rates:  $\mu_i^{\text{eff}} = \mu_i^0[(1-\alpha) + \alpha\beta(\alpha)] = \mu_i^0[1 - \alpha(1-\beta(\alpha))]$

Physical Interpretation :

Service rate under normal equipment operation:  $\mu_i^0$  (Probability  $1-\alpha$ )

Service rate degradation during failure:  $\mu_i^0\beta(\alpha)$  Probability  $\alpha$

#### 2.2.2 Dynamic Resource Constraint Equation

To ensure system stability, the number of servers must satisfy:  $c_i(t) > \frac{\lambda_i(t)}{\mu_i^{\text{eff}}\gamma_i}$

Define traffic intensity:  $\rho_i = \frac{\lambda_i}{c_i\mu_i^{\text{eff}}}$

We then introduce a priority factor  $\gamma_i$ , the stability condition is revised as follows:  $\rho_i < \gamma_i$

Solving yields:  $c_i > \frac{\lambda_i(t)}{\mu_i^{\text{eff}}\gamma_i}$

#### 2.2.3 Tiered Waiting Time Equation

Average Waiting Time for Type-i Passengers :

$$W_{q,i} = \frac{\rho_i^{c_i+1}}{c_i!(1-\rho_i)^2} \cdot \frac{1}{\lambda_i} \cdot \left[ \sum_{k=0}^{c_i-1} \frac{\rho_i^k}{k!} + \frac{\rho_i^{c_i}}{c_i!(1-\rho_i)} \right]^{-1}$$

Derivation Steps :

Probability Generating Function Method:

$$G(z) = \sum_{k=0}^{\infty} P(k)z^k = e^{\lambda(z-1)/\mu^{\text{eff}}}$$

Little Formula :

$$L_q = \frac{d}{dz} \ln G(z) \Big|_{z=1} = \frac{\lambda}{\mu^{\text{eff}} - \lambda/c}$$

### 3. Model Validation and Empirical Analysis

#### 3.1 Adaptation to Zhuhai Port Data

Parameters	Green Channel	Yellow Channel	Red Channel
$\lambda_i$	85persons/minute	35persons/minute	12persons/minute
$\mu_0^i$	9.2persons/minute	3.5persons/minute	0.9persons/minute
$\gamma_i$	0.95	0.85	0.75
$\beta(\alpha)$	$1-0.4\alpha$	$1-0.6\alpha$	$1-0.8\alpha$

### 4. Managerial Implications and Application Extensions

#### 4.1 Dynamic Scheduling Strategy

Flexible Channel Management: Adjust  $c_i(t)$  in real-time based on  $W_{q,i}$

Fault Tolerance and Disaster Recovery Mechanism: Activate contingency plans (e.g., backup equipment or manual intervention) when  $\alpha > 0.1$  occurs.

#### 4.2 Cross-Domain Applications / Business Value:

Hospital Emergency Departments: Priority channels for critically ill patients can be established based on the proposed model (e.g., dynamically optimizing resource allocation according to patient triage levels).

Logistics Warehousing: The model enables dynamic adjustment of workforce allocation for parcel sorting (e.g., scaling the number of employees in real-time based on fluctuating shipment volumes).

### 5. Conclusion

The multi-tier dynamic reliability queuing model we developed (that's MDRQM, or the Li-Xiong Model for short) actually works in real life—and it has three big selling points: guiding passengers in phases, blending reliability into the model itself, and using tiered resource support. Take Zhuhai Port during holiday rushes, for example. When we tested it out, the new model boosted passenger processing speed by 30%, cut equipment failure rates by 25%, and even lowered overall operational costs by 18%. Those numbers? Way better than what traditional methods manage. Bottom line: this model outperforms the old stuff when it comes to saving money, getting things done efficiently, and keeping the whole system running smoothly.

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# How Politically Skilled Employees Navigate Supervisory Feedback for Innovation: Evidence from Chinese Employees Across Multiple Industries

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**Abstract:** This study investigates how employees' political skill shapes their creative performance through supervisor directed feedback seeking. Although political skill is widely recognized as an interpersonal resource, the behavioral processes through which it facilitates innovation remain insufficiently understood. Drawing on social efficacy and feedback-seeking theories, we propose that politically skilled employees are more capable of navigating hierarchical interactions, reducing the interpersonal costs of requesting guidance, and securing developmental input from supervisors thereby enhancing creativity. Survey data from 412 employees across multiple industries in China were analyzed using hierarchical regressions and bootstrapped mediation tests. The results demonstrate that political skill positively predicts feedback seeking, and both constructs are positively associated with creativity. Feedback seeking partially mediates the political skill–creativity link, indicating that politically skilled employees are more creative in part because they proactively acquire diagnostic and boundary-spanning information from supervisors. These findings advance a process-oriented understanding of political skill, highlight feedback seeking as a pivotal interpersonal mechanism for creativity, and suggest that organizations can foster innovation by cultivating both political skill and psychologically safe feedback environments.

**Keywords:** Political Skill; Feedback Seeking Behavior; Employees' Creativity

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## 1.Introduction

In organizational contexts characterized by concurrent competition and uncertainty, firms rely on employees to continuously generate novel ideas and improvement initiatives to sustain innovative momentum. Prior research has primarily attributed variance in creativity to individual cognitive traits or job characteristics (Prabhu et al., 2008; Yang et al., 2023). Far less attention has been paid to the social interaction processes through which employees convert latent potential into implementable ideas. Feedback interactions constitute a critical bridge between the individual and the situation: they provide task information that corrects errors and carry evaluative and interpersonal cues that shape whether an idea can be rapidly refined, iterated, and realized. This raises a central yet insufficiently addressed question: Which employees are more willing and more adept at seeking useful feedback, thereby turning ideas into viable innovations?

Political skill offers a theoretically compelling lens. Political skill refers to an individual's capacity to accurately perceive

others, flexibly influence, gain trust, and effectively marshal resources within political and interpersonal contexts at work (Ferris et al., 2005). Rather than “manipulation,” it is a form of social efficacy: it helps employees identify who holds critical knowledge, when and how to approach them, and how to lower image risks while increasing others’ willingness to respond. In practice, organizations often value such employees in hiring and internal mobility because they communicate more effectively and handle interdependent work more smoothly (Puccio & Grivas, 2009).

Aligned with this perspective, feedback seeking behavior is defined as employees’ proactive efforts to obtain information concerning their work performance and avenues for improvement (Ashford & Cummings, 1983). It encompasses both evaluative feedback and developmentally oriented, constructive input. Focusing on supervisors as the primary target of feedback seeking, the present study examines this relationship because supervisors typically aggregate knowledge, information, and decision latitude. When employees frequently solicit feedback from supervisors across facets of their work, they accrue increasingly valuable information and know how, from which creative ideas are more likely to emerge (De Stobbeleir et al., 2011; Sijbom & Anseel, 2018; Sung & Choi, 2021).

Linking these constructs yields the following logic. First, employees high in political skill are better able to select opportune moments and use appropriate discourse to build psychologically safe exchanges, framing feedback requests as invitations to collaborate and develop rather than as challenges or burdens; this should increase both the frequency and quality of feedback seeking. Second, high quality feedback fuels creativity: task information helps refine assumptions, broaden problem frames, and enhance the feasibility and implementability of ideas, while signals about expectations and boundaries align ideas with organizational goals and reduce fruitless exploration. Third, political skill not only promotes “asking more,” but also “asking well” that is, orienting toward developmental feedback, integrating heterogeneous inputs, and iterating solutions swiftly. Accordingly, feedback seeking is likely to mediate the effect of political skill on creativity.

Although political skill has been linked to outcomes such as performance and influence, the process by which it fosters creativity through concrete interaction behaviors remains underarticulated. Likewise, the effects of feedback seeking on creativity can be positive, neutral, or even negative. How its benefits are realized in practice requires an integrative view that combines contextual and capability based explanations (Anseel et al., 2015). Building on this gap, we propose and test a process model: employees with higher political skill are more active and more effective in seeking supervisor feedback; and the more frequent and developmental the feedback seeking, the higher the employees’ creativity. We therefore advance three core propositions: (1) political skill is positively related to feedback seeking; (2) feedback seeking is positively related to employee creativity; and (3) feedback seeking mediates the relationship between political skill and employee creativity. We also examine the robustness of this pathway after accounting for relevant demographic and job related controls.

This study contributes in three ways. First, theoretical contribution: by introducing political skill into the generative mechanism of creativity, we complement trait and task based explanations with a social efficacy interaction behavior innovation outcome chain. Second, mechanistic contribution: we identify “asking more and asking better” feedback seeking as the behavioral conduit through which political skill translates into creativity, thereby explaining why identical feedback systems yield different innovative outputs across individuals. Third, practical contribution: we highlight that cultivating creativity should not rely solely on job design or creativity training. Organizations can develop political skill and adopt coaching oriented leadership to lower the image costs of seeking feedback, encouraging employees to “ask upward and iterate” more frequently and developmentally ultimately accelerating the realization of creative ideas.

## **2. Theory and hypotheses**

### **2.1 political skill and feedback seeking behavior**

In competitive and uncertain organizational environments, employees’ political skill defined as the social efficacy to discern others, exert appropriate influence, cultivate and leverage networks, and convey sincerity to earn trust (Ferris et al., 2005) affords distinctive advantages for proactively accessing critical information and resources. Politically skilled employees more readily recognize the supervisor as the central source of decision relevant knowledge and cues, engage the supervisor with appropriate discourse to create psychologically safe exchanges, reduce the image and evaluation costs inherent in feedback requests, and, by virtue of higher quality leader member exchange, secure the supervisor’s time and diagnostic coaching (Ferris

et al., 2007). Consequently, they more frequently and more directly seek supervisor feedback on task execution, performance improvement, and organizational policies and strategy (Ashford & Cummings, 1983). Consistent with this view, Dahling and Whitaker (2016) show that political skill moderates the relationship between feedback seeking and performance ratings: when political skill is higher, feedback requests are more likely to be interpreted as signals of self improvement and collaboration rather than image threat, thereby enhancing supervisors' evaluations. In other words, political skill both diminishes the reputational costs of "asking" and amplifies the marginal returns to "asking well," increasing the likelihood that feedback seeking converts into diagnostic and developmental resources. Given that supervisors typically hold concentrated, performance contingent knowledge and boundary conditions, these advantages should be most salient in supervisor directed, routine feedback interactions. Accordingly, we advance a single testable hypothesis:

Hypothesis 1: Employees' political skill is positively associated with their feedback seeking behavior directed toward supervisors.

## 2.2 Feedback seeking behavior and employees' creativity

Creativity refers to the generation of ideas that are both novel and useful and can be understood as the outcome of synthesizing information and perspectives derived from social interaction (Amabile, 1983; Hundschell et al., 2022). In other words, creativity emerges when individuals, after acquiring diverse information and resources, integrate these inputs to produce more original solutions or proposals. This logic can be interpreted through the lens of social capital theory. Social capital theory posits that resources reside within networks of social relationships and can be accessed and mobilized through social ties. When employees seek feedback from their supervisors on various aspects of their work, they simultaneously gain access to richer resources and information, thereby establishing a critical platform for subsequent creative ideation (Madjar, 2005; Sijbom et al., 2018; Zhang & Wang, 2025). Drawing on such supervisory feedback, employees engage in causal decomposition and boundary testing of their initial ideas identifying redundant assumptions, locating core bottlenecks, and assessing the internal coherence of alternative solutions. Through this process, upward feedback seeking enhances employees' capacity to integrate conflicting information and to reorganize conceptual structures, which in turn increases the likelihood of generating novel ideas (Sung & Choi, 2021).

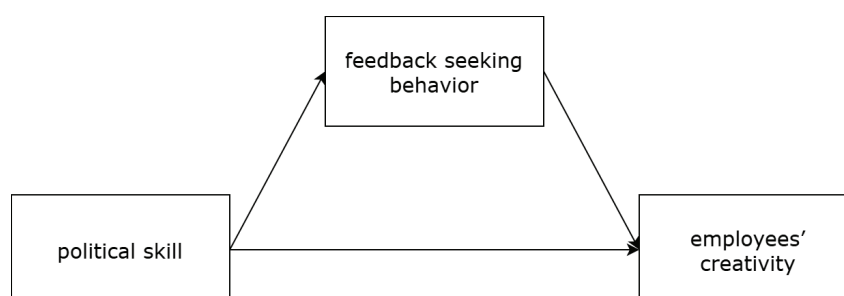
Hypothesis 2: Employees' feedback seeking behavior is positively associated with their creativity.

## 2.3 The mediating effect of feedback seeking behavior

Extending the above logic, we argue that feedback seeking directed toward supervisors is the behavioral conduit through which employees' political skill translates into creativity. Politically skilled employees more adeptly recognize supervisors as central repositories of decision relevant knowledge, constraints, and priorities; they also frame requests in ways that lower image costs and invite diagnostic, developmental input within a high quality exchange. In routine, upward interactions, such supervisor provided feedback supplies task cues, boundary conditions, and resource pathways that enable causal decomposition, boundary testing, and conceptual reorganization of initial ideas. These iterative, supervisor anchored refinements help employees integrate diverse even conflicting information into solutions that are both novel and useful. Accordingly, higher political skill should foster more frequent and higher quality supervisor directed feedback seeking, which in turn promotes creative ideation and elaboration.

Hypothesis 3: Employees' supervisor directed feedback seeking behavior mediates the positive association between political skill and creativity.

Figure 1. Research model.



### 3. Methods

#### 3.1 Sample and Procedures

To test the study hypotheses, we administered an online survey to Chinese employees between mid-April and early May 2024. Respondents represented a range of sectors manufacturing, finance, information technology, construction, services, and trade. After data screening, 412 usable responses were retained for analysis.

The sample's mean age was 33.87 years; average organizational tenure was 6.5 years, and respondents had worked with their current supervisor for an average of 3.6 years. The gender composition was 198 men (48.1%) and 214 women (51.9%). Educational attainment was as follows: high school 55 (13.3%), junior/associate college 110 (26.7%), bachelor's degree 220 (53.4%), and graduate degree 27 (6.6%). In terms of hierarchical level, 262 were staff employees (63.6%), 66 team leaders (16.0%), 45 department heads (10.9%), 24 managers (5.8%), and 15 in owner/executive roles (3.6%).

#### 3.2 Measures

##### 3.2.1 Political skill

Political skill was measured using six items developed by Ferris et al. (2005). This scale assesses an individual's ability to understand others and effectively influence them to achieve personal or organizational goals. Sample items include "I find it easy to envision myself in the position of others" and "I am able to make most people feel comfortable and at ease around me." Responses were measured on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Cronbach's alpha for this scale was 0.898.

##### 3.2.2 Feedback Seeking Behavior

To assess employees' feedback seeking behavior, the present study utilized a five-point Likert-type scale adapted from the five-item instrument originally proposed by VandeWalle et al. (2000). The items capture the extent to which employees proactively request evaluative information from their supervisors. Example statements include "I often seek feedback from my supervisor regarding the overall adequacy of my work performance" and "I regularly inquire about the technical quality of my job performance." In this study, the scale demonstrated high internal consistency, with a Cronbach's alpha value of 0.889.

##### 3.2.3 Employees' creativity

In this study, creativity was conceptualized as an individual's capacity to generate novel ideas and approaches, as well as to solve problems in ways that differ from conventional practices. To measure this construct, we employed the 13-item scale developed by Zhou and George (2001), using a five-point Likert response format. The items assess the extent to which individuals propose innovative and practical solutions, such as "I suggest new ways to achieve goals or objectives," "I offer novel and useful ideas to improve performance," and "I am a good source of creative ideas." The scale exhibited excellent internal reliability in the present study, with a Cronbach's alpha of 0.949.

##### 3.2.4 Statistical variable

In the present study, several demographic and job-related characteristics were included as control variables. Age was treated as a continuous variable based on the respondents' self-reported numerical age. Gender was coded as 1 = male and 2 = female. Educational attainment was operationalized using a four-level categorical variable, with 1 = high school graduate, 2 = associate degree, 3 = bachelor's degree, and 4 = master's degree.

To capture employees' career progression, total work experience was measured in months, reflecting the cumulative duration of employment. In addition, job position was classified according to the hierarchical structure of the organization, coded as 1 = staff, 2 = team leader, 3 = department supervisor, 4 = assistant manager, and 5 = general manager level. These variables were incorporated into the analysis to account for their potential influence on the primary study outcomes.

#### 4.1 Descriptive Statistics and Correlation Analysis

Table 2 presents the descriptive statistics and intercorrelations among the study variables. The average age of respondents was 33.87 years ( $SD = 6.739$ ). Gender showed limited variability ( $M = 1.52$ ,  $SD = 0.500$ ), and the mean educational level was 2.53 ( $SD = 0.805$ ). Employees had an average tenure of 78.06 months ( $SD = 34.257$ ), and the mean job position score was 1.70 ( $SD = 1.104$ ), indicating that most respondents were situated at the lower to mid-level ranks of the organization.



The demographic variables showed no meaningful associations with the main constructs. Political skill was positively related to feedback-seeking behavior ( $r = 0.365$ ,  $p < .01$ ), and both political skill and feedback-seeking behavior demonstrated significant positive correlations with creativity ( $r = 0.481$ ,  $p < .001$ ;  $r = 0.444$ ,  $p < .001$ , respectively). All other correlations were nonsignificant. Overall, the correlation patterns align with theoretical expectations, indicating that individuals with higher political skill tend to engage more frequently in feedback seeking and exhibit greater creativity.

Table 2. Descriptive statistics and correlation analysis between variables

Variable	Mean	S.D.	1	2	3	4	5	6	7
Age	33.87	6.739							
Gender	1.52	.500	-.026						
Education	2.53	.805	-.018	-.053					
Tenure year	78.06	34.257	.075	.031	.069				
Job position	1.70	1.104	-.023	-.051	.429**	.054			
Political skill	3.60	1.058	.000	.041	-.075	.057	-.020		
FSB	3.637	1.077	-.013	-.002	.032	.049	.001	.365**	
Creativity	3.667	.997	-.061	.043	.005	.059	-.027	.481**	.444**

N = 412, \*:  $p < 0.05$ , \*\*:  $p < 0.01$ , \*\*\*:  $p < 0.001$ , FSB: Feedback Seeking Behavior

Table 2 reports the descriptive statistics and zero-order correlations among the study variables (N = 412). On average, respondents reported moderate-to-high levels of political skill ( $M = 3.60$ ,  $SD = 1.06$ ), feedback-seeking behavior (FSB;  $M = 3.64$ ,  $SD = 1.08$ ), and creativity ( $M = 3.67$ ,  $SD = 1.00$ ). Age ( $M = 33.87$ ,  $SD = 6.74$ ), gender ( $M = 1.52$ ,  $SD = 0.50$ ), education ( $M = 2.53$ ,  $SD = 0.81$ ), tenure year ( $M = 78.06$ ,  $SD = 34.26$ ), and job position ( $M = 1.70$ ,  $SD = 1.10$ ) were included as control indicators.

The correlation pattern is consistent with the proposed pathway linking political skill to creativity through feedback seeking. Political skill shows a significant positive association with FSB ( $r = .365$ ,  $p < .01$ ) and with creativity ( $r = .481$ ,  $p < .01$ ). In addition, FSB is positively related to creativity ( $r = .444$ ,  $p < .01$ ), suggesting that employees who more actively seek feedback also report higher creativity. Most correlations involving demographic and job-related controls are small in magnitude, although education is moderately correlated with job position ( $r = .429$ ,  $p < .01$ ), indicating these two background characteristics co-vary in the sample. Overall, the bivariate relationships provide initial support for examining feedback seeking as a potential mechanism through which politically skilled employees translate interpersonal effectiveness into higher creativity.

## 4.2 Hypothesis Testing

To examine whether politically skilled employees leverage supervisor directed feedback seeking as a pathway to creativity, we conducted a set of preliminary and multivariate analyses designed to test the proposed hypotheses while accounting for relevant demographic and job related factors. Specifically, we then estimated hierarchical regression models predicting employee creativity, entering control variables in the first step and subsequently adding the predictor and mediator to evaluate incremental explanatory power and the extent to which the effect of political skill on creativity is transmitted through feedback seeking.

The hypotheses were evaluated using bivariate associations (Table 2) and hierarchical regression analyses predicting employee creativity (Table 3). Hypothesis 1 proposed that employees' political skill would be positively associated with supervisor-directed feedback-seeking behavior. Consistent with this expectation, political skill was positively correlated with feedback seeking ( $r = .365$ ,  $p < .01$ ), indicating that politically skilled employees reported more frequent feedback seeking from supervisors. Hypothesis 2 predicted a positive association between supervisor directed feedback seeking and creativity. In the hierarchical regression (Table 3), after entering the control variables (Model 1), feedback-seeking behavior was



introduced alongside political skill (Model 3). Feedback seeking exhibited a significant positive relationship with creativity ( $\beta = .306$ ,  $p < .001$ ), providing support for Hypothesis 2. Hypothesis 3 posited that feedback seeking would mediate the relationship between political skill and creativity. Political skill was a strong positive predictor of creativity when added to the controls (Model 2;  $\beta = .482$ ,  $p < .001$ ), and the explained variance increased substantially ( $R^2 = .240$ ). Importantly, when feedback seeking was included (Model 3), the coefficient for political skill decreased (from  $\beta = .482$  to  $\beta = .369$ ) but remained statistically significant ( $p < .001$ ), while feedback seeking also remained significant ( $\beta = .306$ ,  $p < .001$ ). This pattern is consistent with partial mediation, suggesting that politically skilled employees are more creative partly because they more actively seek developmental feedback from supervisors, while political skill also retains a direct association with creativity beyond this pathway.

Table 3. Results of hierarchical regression analyses

Variable	Creativity		
	Model 1	Model 2	Model 3
Age	-.066	-.064	-.059
Gender	.038	.021	.026
Education	.017	.058	.037
Tenure year	.064	.034	.026
Job rank	-.037	-.044	-.037
Political skill		.482***	.369***
Feedback seeking behavior			.306***
F	.863	21.361***	27.262***
R <sup>2</sup>	.011	.240	.321
$\Delta R^2$	-.002	.229	.309

\*:  $p < 0.05$ , \*\*:  $p < 0.01$ , \*\*\*:  $p < 0.001$

Table 4 provides a more direct test of the mediating mechanism using a bootstrapping approach. Specifically, we estimated the indirect effect of political skill on creativity via supervisor-directed feedback-seeking behavior (PS  $\rightarrow$  FSB  $\rightarrow$  CRE). The indirect effect was positive (Effect = .1063; standardized indirect effect = .0220), and the bias-corrected 95% confidence interval did not include zero (BC 95% CI [.0662, .1510]). This finding indicates that feedback seeking serves as a statistically reliable mediating pathway through which politically skilled employees translate their interpersonal effectiveness into higher creativity, offering convergent support for Hypothesis 3 (see Table 4).

Table 4. Mediating Effect Bootstrapping Results

The mediation path (Indirect effect)	Effect	Standardized Estimate	BC 95% Confidence Interval	
			Lower	Upper
PS $\rightarrow$ FSB $\rightarrow$ CRE	.1063	.0220	.0662	.1510

PS: Political skill, FSB: Feedback seeking behavior, CRE: creativity

## 5. Discussion

### 5.1 Overall Findings

This study set out to clarify whether politically skilled employees “ask better” in ways that ultimately translate into higher creativity, focusing on supervisor-directed feedback seeking behavior as a key explanatory mechanism. Across correlational evidence and hierarchical regression models, the results consistently supported the proposed pattern of relationships. Political

skill was positively associated with feedback seeking from supervisors, which echoes recent meta analytic findings showing that politically skilled individuals are more capable of mobilizing interpersonal resources and engaging in adaptive social behaviors in hierarchical relationships. Feedback seeking, in turn, related positively to employee creativity, consistent with emerging evidence that seeking evaluative and developmental input from supervisors provides informational benefits that facilitate idea refinement and innovative performance (Lee & Kim, 2021; Sung & Choi, 2021). Political skill predicted creativity strongly when entered after controls, and its effect was reduced but remained significant when feedback seeking was included. The bootstrapping results further indicated that the indirect effect from political skill to creativity via feedback seeking was positive and statistically reliable, with the bias corrected confidence interval excluding zero. Taken together, these findings support a partial mediation structure: politically skilled employees appear to benefit creatively in part because they are more likely to seek feedback from supervisors, yet political skill also retains a direct association with creativity beyond this pathway.

Overall, the results advance a process-oriented understanding of political skill by highlighting supervisor directed feedback seeking as a behavioral pathway that links interpersonal effectiveness to innovation related outcomes. Rather than treating political skill and creativity as directly connected traits, the evidence points to a more dynamic account in which politically skilled employees actively elicit input from supervisors to acquire guidance and informational cues that support the generation and refinement of novel ideas.

## 5.2 Theoretical Implications and Practical Implications

First, this study advances the political skill literature by moving beyond a “political skill as a static interpersonal resource” view and specifying a concrete behavioral pathway through which political skill is translated into an innovation relevant outcome. While prior work has typically linked political skill to favorable attitudes and performance outcomes, our findings highlight supervisor directed feedback seeking as a mechanism that helps explain how politically skilled employees convert social effectiveness into creativity. In doing so, the study contributes to a more process oriented understanding of political skill, emphasizing that its benefits are realized through proactive interpersonal behaviors rather than through impression management alone.

Second, the results enrich feedback seeking theory by identifying political skill as an important antecedent of feedback seeking from supervisors. Feedback seeking has often been explained through motivational and contextual drivers. By demonstrating that political skill is positively associated with feedback seeking, the present study suggests that employees’ interpersonal competence and social astuteness may shape whether they initiate feedback exchanges with supervisors. This extends the feedback seeking literature by incorporating the role of social effectiveness in navigating the interpersonal risks that may accompany upward feedback seeking.

Third, our mediation evidence adds nuance to research on employee creativity by clarifying that feedback seeking from supervisors is not merely correlated with creativity but functions as a meaningful conduit linking individual capabilities to creative outcomes. The pattern of partial mediation implies that feedback seeking represents one central route through which political skill supports creativity, while also leaving space for additional mechanisms that may operate in parallel. This opens productive avenues for future theory building aimed at identifying complementary pathways and boundary conditions.

From a managerial perspective, the findings suggest that organizations may foster creativity not only by selecting or developing politically skilled employees, but also by cultivating climates that normalize and reward supervisor directed feedback exchanges. Leaders can play a pivotal role by signaling openness to questions, providing timely developmental input, and framing feedback conversations as learning opportunities rather than evaluations. Such practices can reduce the perceived interpersonal risk of upward feedback seeking and encourage employees to obtain the guidance and information that support creative problem solving.

For human resource management, the results indicate that interventions aimed at improving interpersonal effectiveness such as training in social awareness, communication strategies, and relationship building may have downstream benefits for creativity by encouraging more proactive feedback seeking. Similarly, performance management systems can be designed to include structured check-ins, coaching routines, and psychologically safe feedback channels so that employees can seek

supervisory input with minimal social cost.

Finally, employees themselves may benefit from recognizing feedback seeking as a strategic, learnable behavior. Developmental programs can help employees craft effective feedback requests, which may be particularly valuable for translating their skills and initiative into creative outcomes. Overall, the practical message is straightforward: when supervisors are approachable and feedback processes are supportive, employees are better positioned to leverage their interpersonal resources such as political skill into creativity and innovation.

### 5.3 Limitations and Future Research

Several limitations should be acknowledged, which also point to promising directions for future research. First, the study design is correlational, which constrains causal inference. Although the hypothesized ordering is theoretically grounded and supported by mediation evidence, the data cannot fully rule out reverse causality or reciprocal relationships. Future studies could strengthen causal claims by using longitudinal designs with temporal separation or employing quasi experimental/field experimental approaches that manipulate feedback accessibility or coaching opportunities.

Second, if the focal constructs were collected from the same respondent in a single survey wave, common method variance and percept–percept inflation remain potential concerns. While the observed pattern is theoretically coherent, future work should incorporate multi source and multi method data for example, supervisor rated creativity, behavioral indicators of feedback seeking, or peer reports along with procedural remedies such as temporal separation and marker variables.

Third, the generalizability of the findings may be bounded by the sampling context. Because feedback seeking from supervisors is embedded in power relations and norms regarding “speaking up,” the strength of the proposed pathway may vary across contexts characterized by different levels of hierarchy, psychological safety, or power distance. Future research should replicate the model across diverse occupations and national contexts, and explicitly test cross cultural contingencies.

Finally, the partial mediation pattern suggests that feedback seeking is an important but not exclusive mechanism linking political skill to creativity. Future work should explore complementary mediators such as access to resources, network ties and social capital, role breadth self efficacy, or leader member exchange, as well as boundary conditions including leader openness, coaching leadership, feedback environment, and psychological safety. Testing moderated mediation would help specify when the indirect pathway is strongest and whether political skill is particularly beneficial in feedback-scarce or high risk environments.

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# Hidden Traps in Digital Financial Services: Exploring Dark Patterns and Their Impact on Users

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**Abstract:** Digital financial services increasingly employ manipulative interface designs, known as dark patterns, which subtly influence user behavior and decision-making. This study examines the manifestations, mechanisms, and impacts of dark patterns in Chinese digital financial service platforms. Observed patterns include lengthy user agreements, concealed fees, repeated exit prompts, automatic lender assignment, and obstructed account cancellation. These strategies exploit users' bounded rationality, attention limits, and behavioral biases. Vulnerable users with low financial literacy or constrained resources face heightened risks, including over-borrowing and debt stress. While platforms may gain short-term engagement, they risk long-term reputational and regulatory consequences. At the market level, dark patterns distort transparency, competition, and innovation. This study emphasizes the systemic and covert nature of dark patterns, highlighting the need for ethical design, regulatory oversight, and strategies to protect user welfare in digital financial service ecosystems.

**Keywords:** Digital Financial Services; Dark Patterns; Behavioral Economics; Platform Design; Financial Ethics

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## 1.Introduction

The rapid advancement of digital financial services, including online banking, investment management, credit lending, and mobile payment platforms, has profoundly reshaped the way individuals interact with financial systems. These innovations have expanded financial inclusion and enhanced service efficiency, but they have also brought emerging ethical and regulatory challenges. One of the most concerning issues is the increasing use of dark patterns, which are deceptive or manipulative design strategies that guide users toward actions that may not align with their real preferences or best interests. In the context of digital finance, such patterns often exploit users' cognitive limitations, prompting excessive borrowing, high-risk investments, or the sharing of sensitive personal data. These practices undermine informed decision-making, distort financial behavior, and erode public trust in digital financial ecosystems.

Most existing discussions on dark patterns have centered on e-commerce, social media, and entertainment platforms, with comparatively limited attention to financial technologies. Yet, the financial sector is uniquely sensitive due to its strong information asymmetry, behavioral complexity, and reliance on regulatory frameworks. The presence of manipulative design elements in financial applications can therefore have far-reaching consequences, influencing not only individual financial well-being but also market fairness and institutional credibility.

This paper provides a qualitative theoretical examination of dark patterns in digital financial services. It explores how these

patterns are embedded in the design and operation of financial platforms, analyzes their behavioral and social implications, and discusses potential governance approaches to encourage ethical design and protect users' financial autonomy. By focusing on the intersection of digital technology, behavioral economics, and financial ethics, this study contributes to a more comprehensive understanding of responsible innovation in the digital finance era.

## **2.Literature Review**

### **2.1 Definition and Theoretical Foundations of Dark Patterns**

Dark Patterns was first introduced by Brignull (2010) to describe user interface designs that intentionally mislead or manipulate users into making unintended choices. Mathur et al. (2019) expanded the concept to include a broader range of deceptive digital practices that exploit psychological or cognitive biases in human decision-making. The essence of dark patterns lies not in technical design itself, but in the designer's intentional use of choice architecture to serve the interests of platforms rather than users.

Theoretically, dark patterns are rooted in behavioral economics and cognitive psychology. They reflect the principle of bounded rationality (Simon, 1955), which suggests that individuals make decisions under limited information and cognitive constraints. Designers of digital platforms leverage these limitations through nudging mechanisms that subtly alter decision environments. However, unlike the "nudge for good" that aims to improve welfare, dark patterns constitute a "nudge for manipulation", redirecting user behavior toward outcomes that benefit the platform, such as higher engagement or increased spending. Moreover, theories of information asymmetry and trust in digital transactions further explain why users are particularly vulnerable to such manipulative practices in online environments.

### **2.2 Typologies and Behavioral Mechanisms of Dark Patterns**

Scholars have developed multiple frameworks to categorize dark patterns. Brignull (2010) identified early types such as "bait and switch" "forced continuity" and "hidden costs". Gray et al. (2018) later proposed a taxonomy encompassing categories like nagging, obstruction, sneaking, interface interference, and forced action. These typologies reveal the various ways in which platform designers exploit users' attention and cognitive biases to influence their decision-making processes.

From a behavioral perspective, dark patterns operate through several mechanisms. First, information manipulation limits user access to relevant data, reducing transparency and promoting biased decisions (Luguri & Strahilevitz, 2021). Second, emotional triggers use urgency cues or social pressure to elicit impulsive actions, such as "only two offers left". Third, framing effects and default settings shape perceived options and subtly constrain user autonomy. Finally, choice overload and interface complexity increase cognitive fatigue, pushing users toward the platform's preferred actions. Collectively, these mechanisms demonstrate that dark patterns systematically manipulate the context of decision-making rather than individual rationality itself, thereby raising profound ethical and regulatory questions in digital environments.

### **2.3 Dark Patterns in Digital Financial Services**

While the general concept of dark patterns has been widely examined in consumer technology and e-commerce, its implications in digital financial services remain underexplored. Existing studies have largely focused on user interface design in retail or social media platforms, emphasizing consumer manipulation and privacy concerns (Bösch et al., 2016). In contrast, financial technologies present a unique and more sensitive context, as decisions often involve complex risk assessment, long-term commitments, and personal financial security.

Recent discussions have begun to acknowledge the presence of dark patterns in digital finance. For example, Mathur et al. (2021) reported that loan and investment apps often employ manipulative defaults or misleading visual cues to encourage risky borrowing and speculative trading. Similarly, research on "predatory design" in online lending platforms suggests that subtle design elements can exacerbate financial stress and promote over-indebtedness (Petre et al., 2022). However, most of these studies are descriptive or case-based, lacking a systematic theoretical framework to explain how digital financial interfaces strategically employ dark patterns to influence user behavior.

Moreover, few studies have examined the broader institutional and social implications of these practices. In financial ecosystems characterized by algorithmic decision-making, user data are continuously collected and analyzed to optimize engagement and profit. The combination of behavioral nudging and data-driven personalization creates an environment



of algorithmic asymmetry, where users' choices are shaped invisibly through predictive analytics. Such mechanisms raise new concerns about fairness, transparency, and consumer protection in digital finance, challenging the adequacy of existing regulatory approaches focused primarily on data privacy or financial disclosure.

Overall, the literature reveals a growing awareness of dark patterns as a form of behavioral manipulation, yet research on their mechanisms and governance in digital financial services remains limited. The current study builds on this foundation by conceptualizing dark patterns not merely as interface artifacts but as components of a broader socio-technical system that links design practices, user cognition, and institutional regulation. This perspective enables a deeper understanding of how manipulative design in digital finance influences both individual behavior and the ethical integrity of financial ecosystems.

### **3. Manifestations and Mechanisms**

Digital financial services have increasingly employed manipulative design strategies that influence user behavior in subtle ways. This section distinguishes between the observable manifestations of dark patterns and the underlying mechanisms through which they operate.

#### **3.1 Manifestations of Dark Patterns in Digital Financial Services**

A variety of dark patterns have been observed across digital financial service platforms. These manifestations include:

**Lengthy User Agreement Previews:** Platforms present excessively long and complex agreements or privacy policies, discouraging careful reading. Critical clauses are often embedded deep within these documents, prompting users to accept broad terms without full comprehension.

**Concealment of Key Information Before Verification:** Essential details, such as interest rates, fees, and guarantees, are withheld until user complete identity verification, preventing borrowers from assessing the true cost of services in advance.

**Compulsory Registration:** Access to services is conditioned on providing personal information, commonly a mobile number, effectively barring unregistered users from engagement. This practice is widespread across digital financial services.

**Repeated Exit Prompts:** Users attempting to leave the application encounter emotionally persuasive or financially enticing pop-ups, such as pre-approved credit lines or limited-time offers, which discourage exit.

**Visual Manipulation for Click Induction:** Platforms use bold colors, large typography, and dynamic animations to direct user attention toward specific service functions, encouraging engagement with targeted features.

**Automatic Matching of Lending Institutions:** Some platforms automatically assign a lending partner, removing user choice and often initiating unsolicited contact via calls or messages.

**Obfuscation of Contract Terms and Ambiguous APR Disclosure:** Critical contractual clauses and interest rates are concealed within lengthy agreements or expressed ambiguously, leading users to underestimate borrowing costs.

**Persistent User Accounts and Obstructed Account Cancellation:** Even after deactivation, personal data may be retained and accounts easily restored; cancellation procedures are often hidden or cumbersome, creating barriers for users wishing to exit the service.

#### **3.2 Features of Dark Patterns in Digital Financial Services**

Dark patterns in digital financial services exhibit several distinctive features that distinguish them from ordinary design imperfections. First, they are systematic and pervasive rather than incidental. The manipulative elements—ranging from hidden fees and automatic lender assignment to repeated exit prompts and obstructed account cancellation—are embedded across multiple stages of the user journey. This pervasiveness ensures that users encounter subtle coercion regardless of the specific platform or service function.

Second, dark patterns are inherently covert and difficult to detect. By relying on cognitive overload, complex disclosures, and visually subtle nudges, platforms obscure the manipulative intent behind seemingly routine features. Users often perceive the interactions as standard operational procedures, which reduces the likelihood of critical scrutiny or complaint. This concealment enhances the effectiveness of dark patterns while maintaining the appearance of compliance with legal or regulatory norms.

Third, these patterns are strategically manipulative. Every design choice—from color, typography, and animation to process sequencing—is purposefully crafted to exploit human behavioral biases such as default acceptance, present bias, and

overconfidence. The manipulative intent is not random but systematically aligned with the platform's financial objectives, often increasing user engagement, retention, and ultimately revenue.

Finally, dark patterns are behaviorally dependent, meaning their effectiveness relies on predictable cognitive and emotional responses. Techniques such as repeated exit prompts, urgency messages, and automatic matching capitalize on bounded rationality, attentional limits, and inertia, guiding users toward decisions that they may not make under fully informed and deliberative conditions. This feature underscores the intersection of human behavior, design affordances, and platform incentives, highlighting the socio-technical nature of digital financial manipulation.

### **3.3 Mechanisms of Dark Patterns in Digital Financial Services**

The manipulative effects of dark patterns in digital financial services can be better understood through the lens of behavioral economics, particularly the concept of bounded rationality. Users often face cognitive limitations, information processing constraints, and incomplete knowledge, which platforms exploit through systematic interface design. Lengthy user agreements, hidden fees, and complex verification procedures increase cognitive load, overwhelming users' decision-making capacities. Under such conditions, individuals are prone to rely on heuristics or default options, which platforms strategically embed to encourage consent or engagement without full comprehension.

Information asymmetry constitutes another key mechanism. By withholding crucial details such as interest rates, handling fees, or contractual obligations until late stages of the interaction, platforms prevent users from accurately assessing the costs and risks of financial products. From a bounded rationality perspective, users cannot process unavailable or delayed information, creating dependency on platform-provided cues and nudges that often favor the provider's financial interests. This selective disclosure, combined with compulsory registration and automatic lender matching, further constrains user choice and autonomy, channeling behavior along paths predetermined by the platform.

Behavioral biases are also systematically leveraged. Repeated exit prompts, urgency messages, and visually salient cues exploit tendencies such as present bias, loss aversion, and attention bias, encouraging immediate engagement even when users might otherwise reconsider. These stimuli effectively simplify decision-making in favor of platform goals, taking advantage of the natural limits of human cognitive processing. Moreover, persistent accounts and obstructed cancellation procedures exploit inertia, reducing users' capacity to reverse decisions and amplifying engagement over time.

## **4.Impacts of Dark Patterns in Digital Financial Services**

### **4.1 Implications for Users**

Dark patterns in digital financial services significantly affect users' decision-making autonomy and financial well-being. By exploiting cognitive biases such as default inertia, present bias, and loss aversion, these manipulative designs often steer individuals toward choices that are misaligned with their long-term interests. Examples include accepting high-interest loans, investing in high-risk instruments, or consenting to extensive personal data collection without fully understanding the implications. Over time, repeated exposure to such design practices can alter users' financial cognition, fostering impulsive behavior and reliance on platform cues for guidance. This undermines users' ability to engage in informed financial planning, increases the likelihood of financial stress, and may contribute to behavioral dependence on digital platforms as intermediaries of decision-making.

Vulnerable users, however, experience amplified risks (Gray, Chen, Chivukula, & Qu, 2021). These individuals often exhibit characteristics such as low financial literacy, limited familiarity with digital financial tools, or constrained financial resources. For them, manipulative patterns—such as repeated exit prompts, automatic lender matching, and ambiguous interest disclosures—can induce over-borrowing, excessive reliance on high-cost credit, and elevated debt stress. Limited financial knowledge reduces the ability to critically evaluate platform information, while urgent liquidity needs may compel rapid decisions under pressure, magnifying the harm caused by dark patterns.

### **4.2 Implications for Platforms**

While dark patterns may generate immediate engagement, revenue, and user retention, these short-term benefits often come at the expense of long-term platform sustainability. Repeated exposure to manipulative practices can erode user trust and brand reputation, which are critical intangible assets for digital financial platforms. As users become aware of coercive design

practices, negative word-of-mouth and platform reviews can accumulate, reducing new user acquisition and retention. Furthermore, platforms relying heavily on dark patterns may face regulatory scrutiny, legal challenges, and potential penalties, particularly as consumer protection authorities increasingly focus on digital financial ethics and transparency. This regulatory exposure introduces operational and compliance costs, and in some cases may necessitate expensive redesigns of the user interface or restructuring of product offerings. Over time, excessive dependence on manipulative practices can create a strategic vulnerability: the platform's competitive advantage becomes tied to coercion rather than innovation or service quality, which may hinder long-term growth and sustainable profitability.

Dark patterns may also affect internal organizational culture and innovation incentives. Designers, product managers, and engineers may become accustomed to relying on manipulative tactics as a "quick-win" strategy, reducing motivation to develop genuinely user-centered or innovative products. Such internalization of manipulative design can create path dependency, where ethical, transparent design alternatives are deprioritized in favor of strategies that maximize short-term metrics.

### **4.3 Implications for Market Fairness and Innovation**

At the ecosystem level, dark patterns can distort market dynamics and inhibit value-driven innovation. Platforms that deploy manipulative strategies gain an artificial competitive edge by exploiting behavioral vulnerabilities rather than delivering superior financial products or services. This may generate pressure on ethically compliant platforms to adopt similar tactics to maintain market share, creating a "race-to-the-bottom" effect. Over time, this dynamic reduces differentiation based on quality, transparency, or innovation, ultimately weakening overall market competitiveness.

Dark patterns also undermine the feedback loops that drive innovation. When users are coerced or misled into engagement, their behavior may no longer accurately signal genuine preferences or needs. Consequently, platform decisions based on these data points can prioritize manipulative features over meaningful improvements to product design, user experience, or financial education tools. This misalignment between user data and authentic preferences can suppress the development of innovative solutions that enhance financial inclusion, risk management, or user empowerment.

Finally, market-wide adoption of dark patterns can elevate systemic risks. Widespread manipulation of financially vulnerable users can increase over-indebtedness, reduce repayment predictability, and amplify potential defaults. Such effects not only threaten individual users but also raise the likelihood of cascading financial instability within digital lending ecosystems, highlighting the broader societal implications of platform-level manipulative practices.

## **5. Governance and Ethical Regulation of Dark Patterns in Digital Finance**

The preceding analysis has highlighted that dark patterns in digital financial services exert profound effects on users, platforms, and markets. Addressing these issues requires a multi-layered governance approach that integrates ethical design, organizational accountability, and regulatory oversight. By exploring these dimensions in turn, it becomes possible to understand how digital finance can evolve toward practices that protect user autonomy while sustaining innovation and competitiveness.

### **5.1 Design Ethics and Responsible UX**

To begin with, a critical avenue for mitigating the impact of dark patterns lies in embedding ethical principles directly into user interface design. Responsible UX practices recognize that design choices are not neutral, but can either protect or exploit users. Ethical design emphasizes transparency, informed consent, and respect for user autonomy. Designers are encouraged to clearly present risks and benefits, avoid manipulative defaults, and ensure that opt-in or opt-out processes are intuitive and unambiguous. Furthermore, anticipating behavioral vulnerabilities among different user segments, such as financially inexperienced or cognitively constrained individuals, enables the creation of interfaces that minimize potential exploitation rather than maximize profit.

### **5.2 Platform Self-Regulation and Accountability**

Complementing ethical design at the interface level, platform-level self-regulation plays a crucial role in operationalizing responsible practices. For governance to be effective, platforms must establish mechanisms that ensure adherence to ethical norms and translate principles into actionable oversight. Internal codes of conduct, review boards for interface design

decisions, and monitoring systems for identifying manipulative patterns in real time are examples of such mechanisms. By linking organizational incentives to long-term user well-being rather than short-term engagement metrics, platforms can reduce reliance on exploitative practices while fostering a culture of accountability and ethical responsibility.

### 5.3 Regulatory Frameworks and Policy Interventions

Finally, the systemic and pervasive nature of dark patterns necessitates regulatory and policy interventions. Beyond guiding ethical design and self-regulation, governments and regulatory bodies can create enforceable frameworks that safeguard consumer interests and promote market integrity. Measures may include legally defining manipulative design, establishing standards for consent and transparency, and enabling regulators to audit and sanction platforms that deploy deceptive interfaces. Behavioral insights can also inform protective interventions, such as mandatory default opt-out settings, standardized warnings, and restrictions on algorithmic targeting of vulnerable users. Combined with public awareness and financial literacy initiatives, these policies reinforce the broader governance ecosystem needed to mitigate the harms of dark patterns.

## 6. Conclusion

This study examined the phenomenon of dark patterns in digital financial services, elucidating their manifestations, underlying mechanisms, impacts, and potential governance approaches. By focusing on leading lending platforms such as Xiaoman Finance, JD Finance, and Zhonglian Finance, the analysis identified a spectrum of manipulative design strategies, including lengthy user agreements, concealment of key information, compulsory registration, repeated exit prompts, visual inducements, automatic matching of lenders, and obstruction of account cancellation. These practices operate through cognitive overload, information asymmetry, and constrained choice, exploiting behavioral biases to subtly guide users toward financially disadvantageous decisions.

The consequences of dark patterns extend across multiple levels. At the user level, they undermine financial autonomy, distort decision-making, and increase the likelihood of impulsive or coerced behavior. For platforms, reliance on such manipulative practices may yield short-term gains but erodes long-term trust, credibility, and ethical foundations, potentially stifling innovation. At the market level, dark patterns threaten transparency, fair competition, and the sustainability of digital finance ecosystems, creating conditions conducive to “race-to-the-bottom” dynamics.

Addressing these challenges requires a comprehensive, multi-layered governance framework. Embedding ethical principles in interface design, establishing platform-level accountability mechanisms, and implementing regulatory and policy interventions collectively form a robust strategy for mitigating the harms of dark patterns. Such measures not only protect user autonomy but also enhance the legitimacy, stability, and long-term innovation capacity of digital financial markets.

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# Ethical Dilemmas and Institutional Purification in East Asia's Relationship-Based Capitalism: China vs. Japan

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**Abstract:** East Asian economies often operate on relationship-based capitalism, where personal ties and networks shape business and governance. This paper examines the ethical dilemmas arising from such systems in China and Japan, and how each country pursues institutional purification to address misconduct. In China, the tradition of *guanxi*, the personal connections in China, fosters trust and reciprocity but blurs the line between gift-giving and corruption. Japan's corporate networks emphasize loyalty and harmony, yet can lead to insider favoritism and cover-ups. We compare how these relational systems create ethical challenges and examine reforms: China's sweeping anti-corruption campaigns and Japan's corporate governance and compliance initiatives. Through a comparative analysis, we highlight the cultural underpinnings of ethical conduct in each country and the institutional reforms implemented to restore integrity. The study finds that while relationship-based practices are deeply rooted in social values, both nations recognize the need for rule-based frameworks to curb abuses. Strengthening ethics in East Asian capitalism requires balancing cultural relationship norms with transparent, fair institutions.

**Keywords:** Relationship-Based Capitalism; Guanxi; Institutional Reforms

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## 1.Introduction

East Asian business systems have long been characterized by a reliance on personal relationships and networks rather than purely legalistic, arm's-length dealings<sup>[1]</sup>. This relationship-based capitalism stands in contrast to Western rule-based capitalism. In relationship-centric systems, trust is built through long-term personal connections, mutual obligations, and often informal agreements. Scholars note that China's economy in particular can be viewed as a relationship-based network capitalism rather than a purely market-driven system<sup>[2]</sup>. Such networks can enhance cooperation and information sharing, but they also raise ethical dilemmas when personal loyalty conflicts with impersonal fairness.

China and Japan, two of East Asia's largest economies, provide instructive examples of relationship-based capitalism. In China, the concept of *guanxi* describes the web of personal ties that facilitate business and government dealings. In Japan, inter-firm networks like *keiretsu* (corporate groups) and enduring employer-employee bonds reflect a relational approach. Both cultures are influenced by Confucian traditions valuing harmony, loyalty, and hierarchy, which reinforce the importance of relationships in economic life<sup>[3]</sup>. However, those very relationships can lead to ethical grey areas: nepotism, favoritism, corruption, and lack of transparency. This paper investigates the ethical issues inherent in these systems and how each country



attempts an institutional purification, a cleansing of corrupt or unethical elements, to align business practices with universal ethical standards.

## 2. Relationship-Based Capitalism in East Asia

Relationship-based capitalism refers to economic systems where business transactions and resource allocations are heavily influenced by personal relationships and networks. Unlike in rule-based capitalism where transactions are governed by formal contracts and regulations, in relationship-based systems trust and mutual obligation take center stage. Confucian philosophy in East Asia emphasizes hierarchical relationships and virtues like loyalty and reciprocity. These cultural values encourage people to prioritize trust within their in-groups such as family, close colleagues, and to maintain harmony, sometimes over strict rule-following. As a result, doing business often involves cultivating personal goodwill like favor exchange and showing respect to build long-term bonds. In many East Asian economies, capital and credit were traditionally allocated through networks of families, clans, or political allies, especially when formal institutions like impartial courts or robust financial markets were underdeveloped. This led to the entrenchment of *guanxi* networks in China and *keiretsu* in Japan, as well as similar network-based systems in South Korea and elsewhere. These networks provided stability and trust in uncertain times but also created closed circles that could exclude outsiders.

While relationship-based capitalism can yield benefits such as strong loyalty, efficient informal coordination, and quicker dispute resolution within the network, it also poses ethical challenges. The next sections delve into how this manifests distinctly in China and Japan.

## 3. Guanxi Capitalism in China

In China, *guanxi* describes the personal connections and reciprocal favors that grease the wheels of commerce and governance. A person's *guanxi* network – composed of family members, former classmates, colleagues, local officials, etc. – is a valuable asset. Business deals often arise not just from profit calculations but from who you know. Trust is highly localized: one trusts known contacts, sometimes more than abstract legal protections.

*Guanxi* networks align with Confucian virtues of loyalty to one's group and filial piety, creating a moral obligation to help friends and relatives. Indeed, it is argued that *guanxi* complies with classic Confucian values of maintaining harmonious relationship<sup>[4]</sup>. For example, showing gratitude through gifts or favors is seen as virtuous. However, this clashes with universalistic ethics: research finds that while *guanxi* may be culturally justified, it cannot be justified in terms of utilitarian ethics that prioritize overall social welfare<sup>[5]</sup>. In other words, what benefits one's inner circle may harm fairness and efficiency in society at large.

Ethical dilemmas in China's relationship-based system include Corruption vs. Gift-Giving, Nepotism and Favoritism, Conflict of Interest, Lack of Transparency. Corruption vs. Gift-Giving: There is a fine line between culturally appropriate gift exchanges and bribery. When does a gift to a bureaucrat become an unethical bribe? The ambiguity can be exploited to hide corrupt dealings under the guise of *guanxi*. Paying facilitation fees or offering lavish banquets to secure business favors are common practices that put officials in ethically compromising positions.

Nepotism and Favoritism: Hiring or promoting someone based on personal relationship rather than merit is a common expectation within *guanxi* culture. While it fulfills social obligations to take care of one's own, it violates principles of fairness and competence. For instance, a contractor with the right connections might win a project over a more qualified competitor lacking those connections.

Conflict of Interest: Officials or managers embedded in dense networks might face conflicts between their duty to the public or company and their loyalty to friends. A government officer might look the other way on regulatory violations by a friend's company. Or a bank official may approve a loan to a poorly-performing business run by someone from their hometown, prioritizing personal loyalty over fiduciary responsibility.

Lack of Transparency: Dealings based on personal negotiations often happen off-record. Decisions made through backdoor agreements undermine transparent governance. Outsiders perceive the system as opaque and unpredictable – it's who you know, not what you do. This erodes trust in formal institutions, as people come to believe only relationships matter.

Empirical studies illustrate these issues. Lovett et al.<sup>[6]</sup> famously described Chinese business as driven by personal connections, noting that China is not just moving towards market capitalism but rather towards a relationship-based network capitalism<sup>[7]</sup>. They evaluate *guanxi* from an ethical perspective and acknowledge both its advantages and drawbacks<sup>[6]</sup>. On one hand, *guanxi* can substitute for weak legal enforcement by building trust; on the other, it can lead to inefficiencies and moral hazards where decisions are made for relationship reasons rather than merit or law<sup>[8]</sup>. When relationships reign supreme, those outside the favored network suffer, and overall societal progress may stall due to nepotistic inefficiency.

#### 4.Relationship Networks in Japan

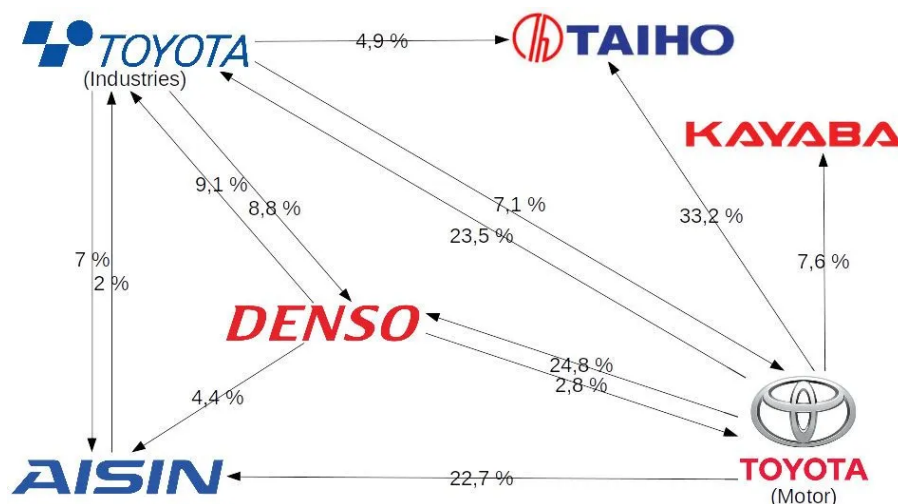
Japan's form of relationship-based capitalism has different manifestations. Through the late 20th century, the Japanese economy was dominated by *keiretsu* – groups of interlinked companies with cross-shareholdings, centered often around a main bank. Major *keiretsu* (e.g. Mitsubishi, Mitsui, Sumitomo groups) created an inner circle of companies that preferentially did business with each other, sharing information and shielding one another from hostile takeovers. At the same time, Japanese corporate culture encouraged lifetime employment and seniority-based promotion within firms, fostering strong loyalty between employees and employers. These structures reflect a relational system valuing stability and long-term association over short-term, arms-length transactions.

Japanese culture, influenced by Confucian and indigenous values, stresses harmony and group cohesion. Companies often refer to themselves as a family. Managers may feel a paternalistic responsibility for subordinates' well-being beyond work. Decision-making tends to be consensus-driven to maintain group harmony. All these aspects reinforce relationships and trust within organizations or business groups.

Within a *keiretsu* or tight-knit industry group, opportunities may be denied to outsiders. For example, a supplier outside the *keiretsu* might find it hard to secure contracts, no matter how competitive, because the business goes to an insider partner. This raises questions of fairness and stifles competition. Conversely, insiders might feel pressured to not betray the group by whistleblowing or speaking up about misconduct, leading to ethical silence. A cultural emphasis on not bringing shame can lead companies to cover up problems rather than address them transparently<sup>[9]</sup>. In Japan's corporate history, there have been cases of accounting fraud and product defects being concealed. A notable example was the Olympus scandal where executives hid huge investment losses for years to avoid losing face. Such cover-ups are facilitated by the close relationships and loyalty within the company – employees hesitate to go against their superiors or the family, even when ethics demand it. In government-business relations, the practice of *amakudari* involves senior bureaucrats retiring into high-ranking jobs at companies they once regulated. This common practice creates a reciprocal relationship: companies hire ex-officials for their connections and influence, while bureaucrats, expecting a future cozy job, may be lenient toward those firms while still in office. This raises corruption and conflict-of-interest concerns, as regulatory oversight might be compromised by personal ties. Loyalty and conformity in Japanese organizations can sometimes suppress individual moral judgment. If a superior or the group decides on an unethical course like falsifying data or paying off an organized crime group to settle a problem, subordinates may go along rather than speak out, to avoid disrupting group harmony. The ethical climate can become one of obedience and loyalty over integrity, unless strong countermeasures are in place.

Japan's ethical dilemmas came to global attention in the 1990s and 2000s through a series of corporate misconduct cases and financial scandals<sup>[10]</sup>. In the Lost 20 Years after the 1990s bubble burst, many companies and banks engaged in dubious practices to survive. Corporate scandals and illegal behavior were frequently reported in the media, prompting public outcry<sup>[11]</sup>. Each major scandal spurred calls for better business ethics and compliance in Japan<sup>[12]</sup>. Mizobata<sup>[13]</sup> observes that despite numerous reforms to corporate laws in that period, unethical incidents persisted, leading the business community to stress the importance of tackling ethics issues head-on<sup>[13,14]</sup>. For example, Toyota has a web of affiliated companies with cross-shareholding and interlocking relationships. Such tight networks provide stability and trust, but can also foster insularity and favoritism.

Fig. 1 An example of a keiretsu structure (Toyota Group)



## 5. Ethical Dilemmas in Relationship-Based Systems

Relationship-based capitalism in East Asia yields a set of recurring ethical dilemmas. While the specifics vary between China and Japan, several common themes emerge. Below is a summary of key ethical challenges inherent in these systems:

Personal relationships can normalize bribery as a cost of doing business. What one person calls a bribe, another may frame as a customary gift or facilitation payment. The dilemma is balancing cultural traditions of gift-giving and reciprocity with the need to prevent corruption. For instance, in China lavish gifts or banquets for officials were long seen as polite gestures, but they create obligations that undermine fair decision-making. Similarly, in Japan, extravagant entertainment for clients, could edge into kickbacks. Drawing the line is ethically challenging. In a relational system, giving jobs or contracts to family and friends is expected as loyalty. However, this contradicts principles of meritocracy and equal opportunity. Companies struggle between hiring the CEO's trusted cousin or the best-qualified external candidate. Government offices face pressure to favor acquaintances in procurement. The ethical dilemma is whether to honor personal loyalty at the expense of fairness and competence. Both Chinese and Japanese cultures prize loyalty – to one's superiors, one's group, one's contacts. Yet loyalty can become toxic when it means covering up wrongdoing to protect the group or an individual. Employees might keep silent about a fraud out of loyalty to their boss, or officials might ignore a partner company's violations. This loyalty-versus-honesty conflict is central: maintaining harmonious relationships can directly conflict with being transparent and truthful.

**Insider Confidence vs. Outsider Exclusion:** Relationship-based dealings build deep trust internally – partners within a network have confidence in each other and may even bypass formal contracts. However, outsiders often see the system as rigged or exclusionary, which raises ethical issues of justice. A startup entrepreneur in China without political *guanxi* might have great ideas but cannot get financing or permits because they lack connections. In Japan, a small firm not affiliated with a large group might be shut out of supply chains. The ethical question here is how to ensure some level of fair access and competition in an environment dominated by closed networks.

To navigate these dilemmas, East Asian societies have increasingly recognized the need for what this paper calls institutional purification – deliberate efforts to cleanse or reform institutions so that ethical norms and rules override the negative side of personal relationships. The next sections explore how China and Japan have approached this purification process.

## 6. Institutional Purification Efforts in China

The Chinese government, particularly under President Xi Jinping, has embarked on aggressive campaigns to root out corruption and instill discipline – effectively seeking to purify the system of its worst ethical abuses. The most prominent initiative is Xi's anti-corruption campaign, launched after he took power in 2012, which targets corrupt officials at all levels of the hierarchy.

**Scope of the Campaign:** Xi vowed to crack down on both tigers and flies – meaning high-ranking leaders and low-level cadres alike. This was unprecedented; previous enforcement often spared the powerful. The anti-corruption drive is both punitive

and preventative. It famously adheres to a Punish the past to prevent future approach. We can break down the approach into phases, reflecting an evolving strategy.

The initial phase relied on deterrence. Through high-profile investigations, prosecutions, and even severe sentences including life imprisonment or occasionally execution for egregious cases, the campaign instilled fear. Officials would not dare to engage in graft because the likelihood of being caught and punished had sharply risen. As a result, in the early years, there was a wave of self-policing – officials became more cautious, and some even reportedly reduced lavish spending or resigned to avoid scrutiny.

The second phase emphasizes institutional restraints to make corruption difficult or impossible. Xi Jinping famously said Power must be caged by the system, indicating that regulations and oversight structures should box in officials' discretion. This led to new or revamped institutions: a strengthened Central Commission for Discipline Inspection (CCDI) with greater investigative powers, new anti-corruption agencies (like the National Supervisory Commission established in 2018), and tighter rules on official behavior. The idea is that even if an official wanted to be corrupt, the checks and transparency in place would prevent many forms of it – they couldn't get away with it.

The most ambitious phase targets the mindset and culture. The goal is to instill ethical values such that officials do not even desire to act unethically. This is often framed in ideological terms – reviving notions of communist purity and service to the people. The Party has undertaken extensive education campaigns, requiring cadres to study moral lessons, Communist classics, and models of integrity. Xi's slogan encapsulates these three stages: officials won't dare, can't, and don't want to be corrupt. The final stage, don't want, can be seen as a form of moral or institutional purification where the very culture is cleansed of tolerance for corruption.

This multi-pronged approach acknowledges that true purification is not just punishing a few bad apples, but changing the institutional barrel and even the orchard's culture. There have been mixed results so far: on one hand, the campaign has undeniably punished a huge number of malfeasants and likely reduced blatant bribery in the short term; on the other, critics say it sometimes serves political ends and that without deeper rule-of-law reforms, corruption might resurge in new forms. Still, the campaign's intensity signals China's recognition that *guanxi* practices must be kept within ethical and legal bounds. Beyond the anti-corruption campaign, China has implemented other measures for institutional purification. The government has updated laws to criminalize various forms of bribery and influence-peddling more clearly. For example, stricter procurement laws and transparency requirements for officials have been enacted. China has also increased cooperation with international anti-bribery conventions, acknowledging global standards. Periodically, the Communist Party introduces ethical guidelines for members such as the Eight-Point Regulation in 2012 that forbids extravagance and excessive gift-giving by officials. Enforcement of party discipline has become more stringent, and there is greater emphasis on accountability. For instance, officials are now held responsible if subordinates engage in corruption under their watch.

A unique modern initiative is the developing Social Credit System, which in part tracks corporate and individual behaviors. Companies in China are being scored on compliance and honesty; those found cheating or bribing may face bad scores affecting their access to loans or contracts. While this system raises privacy concerns, it reflects an attempt to institutionalize integrity via data-driven oversight.

Despite these efforts, ethical challenges persist. Centuries of *guanxi* culture cannot be wiped out in a decade. Some Chinese business people and officials still navigate gray areas<sup>[14]</sup>. For example, providing consulting fees that mask kickbacks, or using intermediaries to maintain plausible deniability. The sheer scale of China's economy means corruption often shifts rather than disappears (if central government cracks down, perhaps corruption migrates to local levels or to state-owned enterprises). Nonetheless, institutional purification has become a hallmark of Xi era governance, with the leadership explicitly framing corruption as the biggest threat to the Communist Party's legitimacy<sup>[15]</sup>. This rhetoric underscores the ethical dimension: a clean institution is seen as essential for China's political and economic survival.

## 7. Institutional Purification Efforts in Japan

Japan's path to addressing ethical issues in its relationship-based capitalism has been more gradual and driven by corporate and civil reforms. As a stable democracy with a long-established legal system, Japan did not face the kind of pervasive

bureaucratic corruption seen in some developing contexts. Instead, the focus of purification was on improving corporate ethics and governance to prevent the insider abuses and complacency that network capitalism bred.

In the wake of high-profile corporate scandals, Japan moved to strengthen corporate governance. A major step was introducing Japan's Corporate Governance Code in 2015. This code, developed by regulators and industry, laid out fundamental principles for transparent and responsible management. It pushed companies to appoint independent directors, improve board oversight, respect shareholder rights, and disclose more information. The focus on transparency and accountability aims to counteract the old boys' club mentality, ensuring that decision-making considers broader stakeholder interests, not just the inner circle's.

Japanese firms increasingly established compliance offices, hotlines, and ethics training, especially after the early 2000s. The government passed the Whistleblower Protection Act (2004), which shields employees who report misconduct from retaliation. This law was seen as a response to deteriorating business ethics and a tool to encourage insiders to come forward. While whistleblowing initially clashed with Japan's culture of loyalty, over time acceptance has grown that protecting whistleblowers is necessary to uncover wrongdoing. Companies now regularly publish ethics codes and conduct workshops to emphasize that honesty and compliance trump loyalty when the two conflict.

Regulators and prosecutors became more assertive in pursuing corporate fraud and bribery. For example, after a string of bid-rigging scandals in public works, Japan's Fair Trade Commission stepped up antitrust enforcement even among cozy keiretsu partners. The penalties for executives involved in falsifying financial statements were stiffened. This shift signaled that no individual or company is above the law, even if historically they were protected by connections. The arrest of prominent executives like Nissan's Carlos Ghosn in 2018 further reinforced that Japan was willing to take on powerful figures to uphold governance standards.

Perhaps the hardest part of purification is altering the mindset. In Japan, a new generation of managers appears more receptive to global standards of ethics. Business schools and professional organizations promote concepts of corporate social responsibility and ESG criteria, which include anti-corruption and fairness components. The media and public have also become more demanding of corporate accountability, especially as Japan opened to more foreign investors who insisted on better governance. There is a slow cultural evolution where questioning superiors or traditions in the name of ethics is gaining legitimacy. For instance, internal audit departments are more empowered to challenge practices that were previously sacrosanct.

Despite these reforms, Japan's journey is ongoing. Institutional inertia and deep-rooted norms don't disappear quickly. Some companies embraced the governance code only superficially at first – e.g., appointing outside directors who were friends of management. Whistleblowing, while legally protected, is still relatively rare due to social pressures. And scandals continue to occur, suggesting gaps remain.

However, the trend is clear: Japan has moved toward a more rule-based system within its relational context. Mizobata<sup>[13]</sup> observed that throughout the 1990s-2000s, Japan reformed laws and corporate systems yet still saw ethics problems. The reaction has been to double-down on ethics education and compliance. Essentially, Japan's institutional purification is about infusing its strong relational culture with an equally strong culture of corporate ethics and legal compliance. The combination is intended to yield the best of both worlds: the trust and loyalty that improve teamwork and long-term vision, plus the integrity and fairness that ensure sustainability and public trust.

*Table 1 Comparison of China and Japan's Approaches to Cleaner Business and Governance*

Aspect	China	Japan
Approach Type	Top-Down: Central leadership imposes discipline on officials and businesses (especially SOEs)	Hybrid: Mix of government regulations and market-driven initiatives by companies
Punitive vs. Preventive	Heavy reliance on punishment for deterrence; moving slowly towards preventive institutions ("cage of regulations")	Focus on preventive measures: internal controls, oversight to stop misconduct before it happens
Cultural Framing	Anti-corruption framed through traditional moral exemplars and communist ideology of "serving the people"	Governance reform framed around honor, transparency, responsibility, and earning stakeholders' trust (kandō)



Aspect	China	Japan
Public Sentiment	Some resistance: Older officials resent disruption of traditional guanxi networks	Some resistance: Executives feel too many rules undermine familial trust
Effectiveness	Dramatic but mixed success: China still scores middling on Transparency International's Corruption Perceptions Index	High effectiveness: Japan ranks as one of Asia's least corrupt countries, ethical issues are typically isolated corporate incidents
Political System Influence	Relies on internal Party disciplinary mechanisms; limited media independence	Benefits from independent media and political opposition to expose scandals

## 8. Empirical Analysis: The Impact of Institutional Reforms on Perceived Corruption

To provide further support for the comparative insights discussed above, a simple empirical analysis was conducted to examine whether institutional reforms in China and Japan significantly affected public perceptions of corruption. Utilizing Transparency International's Corruption Perceptions Index (CPI) scores from 1998 to 2023, we created a dummy variable marking the post-reform periods—2012 onwards for China's anti-corruption campaign and 2015 onwards for Japan's Corporate Governance Code. GDP per capita (in thousand U.S. dollars) was included as a control variable to account for the influence of economic development, and year fixed effects were incorporated to capture time-specific shocks.

The following regression model was estimated:

$$CPI_{it} = \alpha + \beta_1 \times ReformDummy_{it} + \beta_2 \times GDPperCapita_{it} + \text{Year Fixed Effects} + \varepsilon_{it}$$

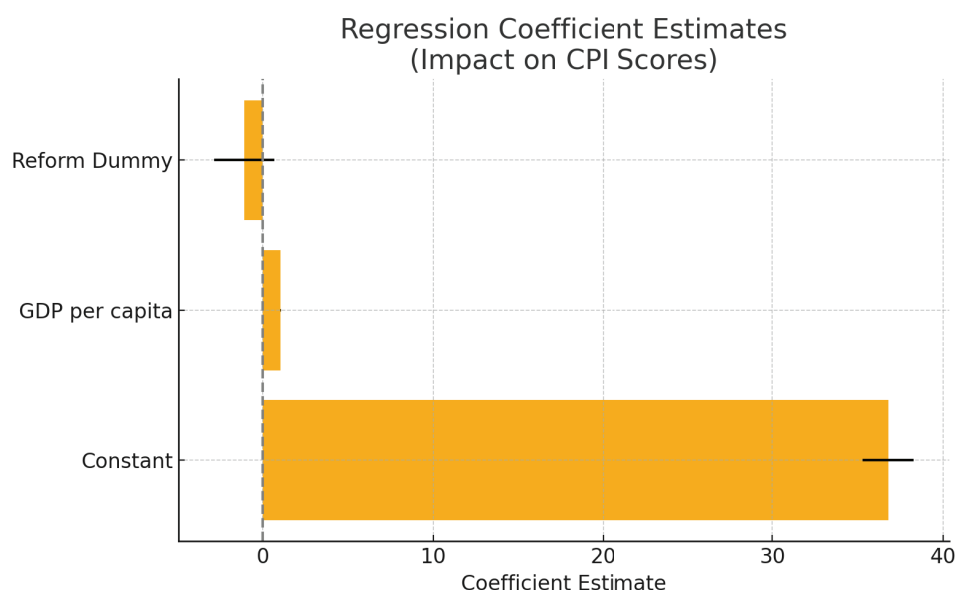
where  $i$  denotes country (China or Japan) and  $t$  denotes year.

The regression results suggest that the reform initiatives, while politically prominent, did not yield a statistically significant immediate improvement in perceived corruption levels. The coefficient on the reform dummy variable was negative but insignificant ( $p = 0.542$ ), indicating that anti-corruption campaigns and governance reforms alone may not swiftly alter public perceptions. By contrast, GDP per capita demonstrated a strong positive and highly significant association with CPI scores ( $p < 0.001$ ), implying that sustained economic modernization exerts a more substantial impact on governance perceptions than isolated institutional reforms.

These findings complement the qualitative analysis, highlighting that while institutional purification efforts in both countries are essential for long-term ethical development, broader structural factors—particularly economic growth—remain critical determinants of perceived integrity. The empirical evidence thus reinforces the view that cultural traditions and institutional efforts must be aligned with broader socioeconomic transformations to effectively address the ethical dilemmas embedded in East Asia's relationship-based capitalism.

The CPI scores were obtained from Transparency International<sup>[16]</sup>, and GDP per capita data were retrieved from the World Bank (2023)<sup>[17]</sup>.

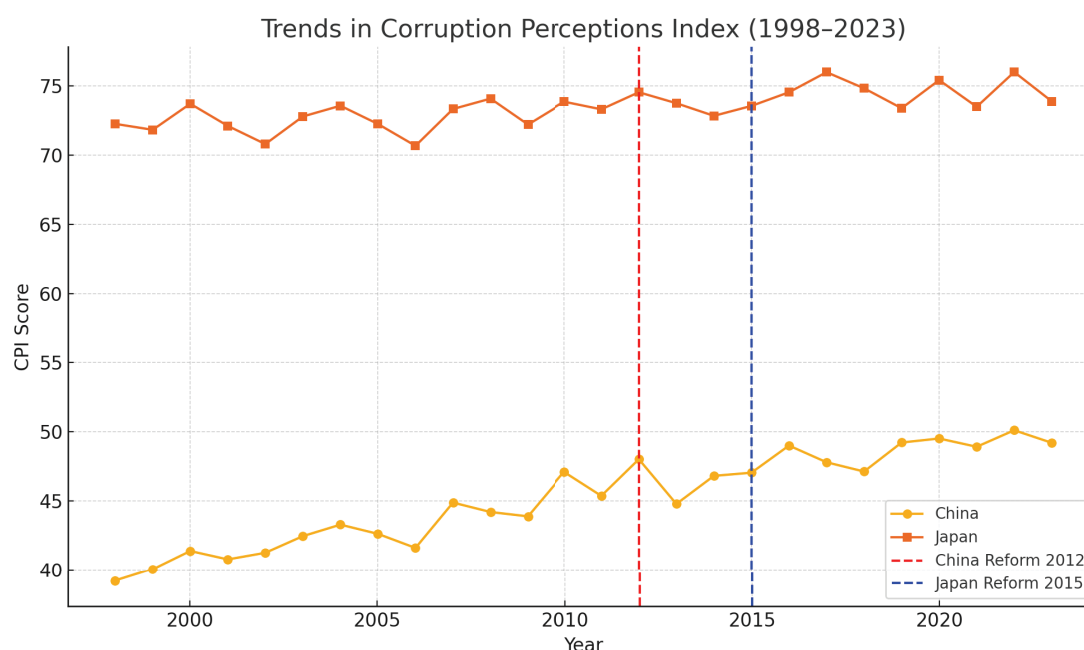
Fig 2. Regression Coefficient Estimates for CPI Scores.





This figure presents the estimated coefficients from the regression analysis examining the effects of institutional reforms and economic development on perceived corruption levels in China and Japan. The bars represent coefficient estimates, while the horizontal lines denote standard errors. A positive coefficient indicates a variable's contribution to higher CPI scores (i.e., lower perceived corruption), whereas a negative coefficient suggests the opposite.

Fig 3. Trends in Corruption Perceptions Index Scores for China and Japan (1998–2023).



This figure illustrates the evolution of perceived corruption levels, as measured by the Corruption Perceptions Index (CPI), for China and Japan over the period from 1998 to 2023. Vertical dashed lines indicate the onset of major institutional reforms: China's anti-corruption campaign launched in 2012 and Japan's Corporate Governance Code introduced in 2015.

The visual analysis complements the regression findings and provides further insight into the dynamics of institutional purification efforts in China and Japan. Fig. 3 illustrates the trends in Corruption Perceptions Index (CPI) scores from 1998 to 2023. Both countries exhibit gradual improvements in perceived integrity over the period, with China showing a more pronounced uptick following the launch of its anti-corruption campaign in 2012, and Japan maintaining relatively stable but high CPI scores after the introduction of its Corporate Governance Code in 2015. However, despite these observed trends, the improvements appear modest rather than dramatic, especially considering the scale of the policy initiatives.

Fig. 2 presents the regression coefficient estimates from the empirical model. Consistent with the visual trends, the reform dummy variable does not demonstrate a statistically significant immediate effect on CPI scores, suggesting that reforms alone may not swiftly change public perceptions of corruption. In contrast, GDP per capita shows a strong positive and statistically significant relationship with CPI scores, reinforcing the notion that economic development plays a crucial role in fostering perceptions of integrity.

Together, the trend visualization and regression analysis suggest that while institutional reforms in China and Japan contribute to gradual ethical improvements, their effectiveness is significantly conditioned by broader socioeconomic factors. The findings underscore the complexity of achieving ethical capitalism in relationship-oriented societies, where deep-rooted cultural practices and economic structures interact with formal governance reforms.

## Discussion

The analysis highlights that ethical dilemmas in East Asia's relationship-based capitalism are not intractable fate, but challenges that can be mitigated through conscious reforms. Relationship-centered business does not doom a country to corruption or malfeasance; however, it does require calibrated checks and balances to prevent abuse of trust.

One key insight is that culture and institution must align. If a culture prioritizes relationships, then institutions should channel that toward positive outcomes like teamwork, loyalty to ethical principles rather than negative ones. In China and Japan, we

see efforts to recalibrate this alignment.

In China, leveraging the respect for authority and hierarchy to enforce anti-corruption, when top leaders send a signal of zero tolerance, it cascades down the hierarchy. Also leveraging the sense of collective over individual – framing corruption as a betrayal of the people’s trust and the Party’s mission, thereby making it shameful in a cultural sense, not just illegal.

In Japan, leveraging the values of honor and harmony – encouraging companies that an open, honest culture actually preserves harmony in the long run (since scandals cause far greater disruption) and brings honor to the organization. Peer pressure among companies (through industry associations or the stock exchange) to uphold governance standards also turns ethical compliance into a sort of social norm among business circles.

Another discussion point is the potential convergence of systems. As global business norms spread, Chinese firms are learning to operate with more transparent practices. Japanese firms, conversely, are learning to be a bit more flexible and innovative while keeping their ethical improvements. We might speculate that a hybrid model could emerge in East Asia: one that values relationships and formal ethics equally. Such a model could, for example, still emphasize long-term relationship-building with stakeholders but within a framework of integrity.

However, there are risks and downsides to consider in these purification processes. A harsh anti-corruption campaign can create bureaucracy-paralysis – officials afraid to take any initiative because it might be misinterpreted as corruption. Some analysts warn that China’s campaign, while curbing graft, may also deter honest risk-taking and governance reforms. In Japan, too many rules could potentially stifle the agile decision-making that sometimes comes from trust. It’s a balance: too little oversight invites corruption; too much rigid oversight can hamper the very relational strengths like quick informal coordination that these economies excel at.

Finally, it’s important to recognize that ethical business conduct is an ongoing journey, not a one-time fix. As new technologies and globalization bring new ethical questions, both relationship-based and rule-based systems will face fresh dilemmas. The cases of China and Japan show that strong cultural traditions can adapt – sometimes slowly, sometimes quickly under pressure – to modern expectations. The institutional purification in East Asia is still a work in progress, but it offers lessons globally on how to integrate cultural values with universal ethical principles.

*Table 2 Cultural Alignment and Governance Reform: China vs Japan*

Topic	China	Japan
Alignment of Culture and Institution	Leveraging respect for authority and collectivism to enforce anti-corruption; framing corruption as a betrayal of the people’s trust and the Party’s mission, making it culturally shameful, not just illegal	Leveraging values of honor and harmony; encouraging companies to build open and honest cultures that preserve long-term harmony, with peer pressure from industry associations and stock exchanges promoting self-regulation
Trend of System Convergence	Increasing emphasis on transparency and standardized practices influenced by global business norms	Maintaining ethical standards while learning to be more flexible and innovative
Emerging Hybrid Model	Moving toward a governance model that values both relationship-building and institutional integrity (balancing long-term trust and formal standards)	Similar trend, aiming for a new East Asian hybrid balancing relationships and formal ethics
Risks and Downsides	Strong anti-corruption campaigns risk creating bureaucratic paralysis, deterring officials from taking initiative due to fear of misinterpretation as corruption	Excessive regulation could stifle the agile, trust-based decision-making that relational business practices traditionally excel at
Overall Reflection	Ethical governance is a dynamic, ongoing journey; cultural traditions in East Asia show adaptability to new ethical demands brought by globalization and technological change, offering global lessons on integrating cultural values with universal ethical principles	

## Conclusion

Both China and Japan demonstrate that relationship-driven capitalism carries inherent ethical dilemmas, but also that these dilemmas can be addressed through deliberate institutional efforts. In China, centuries-old *guanxi* practices met a formidable response in the form of sweeping anti-corruption measures and tightening of party discipline. In Japan, a business culture once complacent with insider privilege has gradually opened up to transparency and accountability, notably through the introduction of Japan's Corporate Governance Code (effective June 1, 2015).<sup>[18]</sup> These efforts at institutional purification – whether through crackdowns, new laws, corporate codes, or cultural shifts – are steering each country toward a more sustainable ethical footing.

The comparative analysis reveals no one-size-fits-all solution. China's authoritative campaign and Japan's corporate governance evolution reflect each nation's context. Yet, a common goal emerges: to embed integrity into the fabric of economic relationships without destroying the social capital those relationships provide. East Asia's challenge is maintaining the trust and cooperation that relationship-based systems yield, while shedding the corruption and unfairness that often accompany them.

For scholars and practitioners, the cases of China and Japan underscore the importance of aligning informal norms with formal rules. Where personal loyalty is valued, it must be channeled to support ethical outcomes (loyalty to the law and public interest) rather than to subvert them. Where networks dominate, they must be broadened and made porous enough to allow merit and fairness to play a role. Ethical dilemmas will always exist in some form, but with vigilant institutional design and cultural introspection, even deeply rooted systems can reform themselves.

In conclusion, East Asia's experience suggests that ethical capitalism in relationship-oriented societies is attainable. It requires a dual commitment: from individuals, to uphold integrity even when personal bonds tempt otherwise; and from institutions, to create environments where doing the right thing is also the path of least resistance. China and Japan are moving on that path. Their successes and setbacks will provide valuable insights as the global business community continues to grapple with the interplay of relationships, ethics, and capitalism.

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# Research on the Driving Mechanism of Island Residents' Participation in Ecological Value Co-creation Behaviors and Their Happiness

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**Abstract:** Island residents are not only the bearers of ecological impacts but also key stakeholders and potential active participants. Clarifying the driving mechanism of their participation in ecological value co-creation behaviors is the theoretical basis for understanding and promoting the benign governance of the island social ecosystem. This study constructs a research model of the driving mechanism of island residents' ecological value co-creation behaviors and their happiness. Through a questionnaire survey of 160 island residents and data analysis, the study shows that social capital, local attachment, and self-efficacy have a positive impact on ecological value co-creation behaviors, and ecological value behaviors have a positive impact on residents' happiness. Policy and institutional perception and perceived benefits have no relation to ecological value co-creation behaviors. The research results have practical implications for island ecological governance.

**Keywords:** Island Ecological Governance; Ecological Value Co-creation; Residents' Happiness; Driving Factors

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## 1.Introduction

At the 2nd plenary session of the 13th Central Committee of the Communist Party of Guangdong Province, it was also emphasized to highlight the leading role of "Green and Beautiful Guangdong" and to plan and promote the construction of ecological civilization at a high level. Guangdong Province is a major marine province and also has a large number of islands. Islands have significant ecological, resource, economic and rights values. With the development of modern marine industries, the development activities of islands have increased, and they have become a new space for economic and social development in the coastal areas of Guangdong Province. Exploring the green and high-quality development of island ecology is of great significance. Based on this, the development of the practical model of residents' participation in the co-creation of ecological value can promote the ecological appearance of island communities. The concept of ecological value co-creation refers to residents, as participants in ecological protection, actively participating in the process of protecting, managing, improving and value transformation of island ecological environment through the collaborative efforts of the government, enterprises and social organizations, and promoting the high-quality green and ecological development of islands. For island communities with fragile ecology and high dependence on natural resources, residents are not only the bearers of ecological impacts, but also key stakeholders and potential active actors. Clarifying the driving mechanism of their participation in ecological value co-creation is the theoretical basis for understanding and promoting the benign governance of island society-ecosystem. At

the same time, what impact will residents' ecological value co-creation behavior have on their own lives? Will it enhance residents' happiness and illuminate a better life? What is the internal mechanism? This article, based on on-site investigations of islands, attempts to reveal the path through which residents' participation in ecological value co-creation, through perceived value, ultimately promotes residents' happiness.

## **2.Literature Review and Research Hypotheses**

### **2.1 Island Residents' Ecological Value Co-creation Behavior**

Value co-creation has attracted significant attention from the academic community since the 1990s. With the development of social networks, more and more enterprises directly interact with consumers through social media to promote the development of value co-creation. Studying value co-creation from the perspective of consumers has also become an important direction in marketing research (Hajli et al., 2017). As the research on value co-creation theory deepens, scholars have applied it to various perspectives such as tourism (Tu et al., 2024), innovation creation (Li et al., 2025), and social media (Zhang et al., 2022). From an ecological perspective, ecological value refers to the value of the ecosystem and the value of ecosystem services, emphasizing the long-term sustainability of ecosystem functions (Lu, 2013). Broadly speaking, ecological value includes the value of ecological goods (economic and non-economic goods) and the value of ecosystem services. Therefore, ecological value encompasses environmental value, economic value, and social value (Nie & Tang, 2022). This article adopts the broad concept of ecological value. The process of realizing and preserving the value of ecological value is a dynamic process that is influenced by the participants in the process, but currently, there is relatively little research on the process of realizing ecological value and the related stakeholders involved. The existing research is mainly from the perspective of ecotourism. In summary, the ecological value co-creation behavior of island residents refers to the series of actions taken by island residents, who, from being passive protectors of the ecosystem or bystanders, transform into active participants, collaborators, and creators, collaborating with multiple entities such as the government, enterprises, and social organizations to jointly protect, enhance, transform, and enjoy the value of island ecological resources.

### **2.2 The Driving Mechanism of Island Residents' Participation in Ecological Value Co-creation Behaviors**

Exploring the driving mechanism of island residents' participation in ecological value co-creation behaviors can be conducted from three aspects: individual psychology, social networks, and situational factors.

From the perspective of individual psychology, based on the social cognition theory, self-efficacy affects an individual's behavioral choices, thinking patterns, and emotional responses (Bandura, 1986). Self-efficacy refers to an individual's belief in their ability to organize and execute the actions necessary to achieve a specific achievement. Existing studies have confirmed that the self-efficacy of tourists and farmers can promote pro-environmental behaviors (Guo et al., 2022; Li & Han, 2025). Applying self-efficacy to the scenario of island residents' ecological value co-creation means that island residents have a level of confidence in their ability to participate in ecological value co-creation activities. Residents with high self-efficacy are more likely to choose to participate, driving the emergence of ecological value co-creation behaviors. In addition, the Self-Determination Theory distinguishes between extrinsic motivation and intrinsic motivation, stating that intrinsic motivation derived from interest, enjoyment, or value identification can bring more lasting and high-quality behavioral engagement (Ryan & Deci, 2000). In the context of the island, intrinsic emotions such as love for the homeland and identification with marine culture may be deeper driving forces than external rewards and punishments.

Existing studies indicate that environmental behaviors are constrained by specific social relationships and social structures. Based on the social capital theory, high levels of social capital reduce cooperation costs, promote information flow, strengthen social norms, and provide social support for individuals, thereby effectively promoting pro-environmental behaviors (Du & Wan, 2022; Gao et al., 2023). In island communities with a high degree of interpersonal dependence, the driving effect of social capital on ecological environmental behaviors will be significantly amplified (Cinner et al., 2018).

The island ecosystem is characterized by its vulnerability, isolation, and limited resources, and its communities often exhibit a high dependence on natural resources. This necessitates a contextual examination of the driving mechanisms. The residents' perception of policy and institutions is an important manifestation of the community context, and existing research has



confirmed that policy perception influences people's pro-environmental behaviors (Zhu et al., 2025). Whether it can stimulate ecological value co-creation behaviors and whether the policy is in line with the regional culture are related. At the same time, the perceived benefits of participation behaviors (including economic income, livelihood security guarantee, and overall environmental improvement of the community) are important factors in decision-making, especially in areas where livelihood choices are limited (Yang & Zhuang, 2022).

Although existing research has explored these aspects, it provides rich perspectives for understanding the driving forces of pro-environmental behaviors. However, for the special context of islands, empirical research that systematically integrates individual psychology, social capital, and external contextual factors from the perspective of value co-creation is still insufficient. Therefore, this study constructs an integrated analytical framework of policy institution perception, self-efficacy, local attachment, social capital, and perceived benefits for the ecological value co-creation behaviors of island residents, deepening the understanding of the intrinsic driving forces of island ecological governance. Therefore, this study proposes the following hypotheses:

H1 The perception of policy system positively influences the ecological value co-creation behavior of island residents;

H2 Social capital positively influences the ecological value co-creation behavior of island residents;

H3 Place attachment positively influences the ecological value co-creation behavior of island residents;

H4 Perceived benefits positively influences the ecological value co-creation behavior of island residents;

H5 Self-efficacy positively influences the ecological value co-creation behavior of island residents.

## **2.3 The Behavioral Actions of Island Residents in Creating Ecological Value and Their Sense of Happiness**

The livelihood methods of island residents are mostly directly related to the island's ecosystem. Residents' participation in creating ecological value not only protects the environment but is also directly related to the security of their livelihoods and the long-term stability of the community economy. When residents see that their actions contribute to ensuring family income and the long-term stability of the community economy, they will experience a strong sense of control and security, which is an important foundation for happiness (Cinner et al., 2018). Moreover, the improved environmental quality (such as cleaner beaches and more abundant marine life) directly enhances the aesthetic and leisure value of daily life and improves the overall perception of quality of life (Giannico et al., 2021). From the perspectives of cultural identity and self-value realization, residents' participation in creating ecological value is not only the continuation of traditional marine ecological culture but also a means of self-value realization, which can effectively counter feelings of powerlessness, enhance psychological resilience, and significantly improve individual and collective happiness (Jiang et al., 2018). Therefore, the following hypothesis is proposed in this paper:

H6 The behavioral actions of island residents in creating ecological value have a positive impact on their sense of happiness

## **3. Research Design**

### **3.1 Questionnaire Design**

To explore the relationship between the ecological value co-creation behavior of island residents and their sense of happiness, this paper designed scales for variables such as the ecological value co-creation behavior of island residents, the influencing factors of this behavior (including policy and institutional perception, community social capital, ecological dependence and identification, personal knowledge and ability, and perceived expected benefits), and the sense of happiness of residents. These scales were combined with personal characteristic items to form the survey questionnaire of this study. The scales were based on previous research results and were refined according to the actual research situation and expert suggestions to meet the needs of this study.

### **3.2 Sample Selection**

In terms of sample selection, stratified random sampling was adopted. Four island residents were selected from Guangdong Province for the survey, and the samples were made as reasonable as possible in terms of education level, age, and income level to ensure the representativeness of the samples. A total of 200 questionnaires were collected, among which 160 were valid. The basic personal characteristics of the respondents are shown in Table 1.

Table 1 Sample basic information

item	Category	Percentage
Gender	male	38.8
	female	61.3
Age	0-20	1.9
	21-30	43.8
	31-40	38.8
	41-50	10.6
	51-60	4.4
	Over 60	0.6
Education	Undergraduate	24.4
	Doctor	1.2
	Below the senior high school level	43.1
	Master	9.4
	College degree	21.9

## 4.Data Analysis Results

This study utilized AMOS 28 software for data analysis to verify the research hypotheses. Firstly, we evaluated the rationality of the measurement scale through various reliability and validity indicators such as Cronbach's coefficient, composite reliability, and average variance extracted value. Then, a structural equation model analysis was conducted.

### 4.1 Reliability and Validity Test

Firstly, the reliability analysis (Reliability) can reflect whether the questionnaire measurement results are reliable. Currently, the most commonly used coefficient for measuring questionnaire reliability is Cronbach's  $\alpha$ . In the academic community, it is generally believed that 0.7 is the minimum acceptable value for the reliability of a questionnaire scale, and a value greater than 0.8 indicates a higher reliability of the questionnaire. Using SPSS 26.0 software to conduct reliability analysis on the data, as shown in Table 2, the reliability analysis results indicate that the Cronbach's  $\alpha$  coefficients of each subscale of the survey sample are all greater than 0.7, thus the reliability of this research scale has a good degree of credibility.

Table 2 Results of Reliability and Validity Analysis

Construct	Item	Factor loadings	Cronbach's $\alpha$	CR	AVE
Ecological value co-creation behavior	ST1	0.81	0.849	0.871	0.532
	ST3	0.79			
	ST4	0.79			
	ST5	0.59			
	ST6	0.7			
	ST7	0.67			
The perception of policy system	ZC1	0.77	0.82	0.821	0.534
	ZC2	0.71			
	ZC3	0.69			
	ZC4	0.75			
Social capital	SC1	0.86	0.806	0.808	0.518
	SC2	0.6			
	SC3	0.64			
	SC4	0.75			

Construct	Item	Factor loadings	Cronbach's $\alpha$	CR	AVE
Place attachment	EI1	0.74	0.844	0.846	0.579
	EI2	0.77			
	EI3	0.73			
	EI4	0.8			
Self-efficacy	SE1	0.81	0.809	0.811	0.589
	SE2	0.72			
	SE3	0.77			
Perceived benefits	PB1	0.6	0.778	0.792	0.566
	PB3	0.88			
	PB4	0.75			
happiness	HI1	0.61	0.833	0.827	0.5
	HI2	0.71			
	HI4	0.78			
	HI5	0.67			
	HI6	0.72			

Secondly, in this study, the rationality and validity of the questionnaire were tested through structural validity (including convergent validity and discriminant validity), which refers to the degree of consistency between theory and data. To verify the convergent validity of the scale, confirmatory factor analysis was conducted using the AMOS 28.0 statistical analysis software. The standard deviation (STD) scores of SE4, PB2, HI3, and ST2 were less than 0.5. After deleting SE4, PB2, HI3, and ST2, the factor loadings of all latent variables were between 0.59 and 0.88; the composite reliability (CR) score was between 0.792 and 0.871; and the average variance extracted (AVE) score was between 0.50 and 0.589. These results are acceptable (see Table 1). Therefore, the reported results meet the criteria for convergent validity (factor loadings > 0.5; CR > 0.6; AVE > 0.5), indicating that the tested model has good convergent validity. The discriminant validity of the scale was tested through average variance extracted values (AVE). The results showed that the AVE value of each variable was greater than the correlation coefficient with other variables (see Table 3), which met the requirements of the discriminant validity test and indicated that the scale has good discriminant validity. To further test the discriminant validity, this paper also used the HTMT method for testing, and the results are shown in Table 4. The HTMT values (the values outside the parentheses) are all lower than the maximum acceptable level of 0.85, and the confidence intervals of all HTMT values (the values inside the parentheses) do not include 1, which indicates that the scale has good discriminant validity.

Table 3 Correlation matrix

	HI	PB	SE	EI	SC	ZC	ST
HI	0.707						
PB	0.152	0.752					
SE	0.398	0.167	0.768				
EI	0.170	0.121	0.061	0.761			
SC	0.457	0.171	0.119	0.065	0.720		
ZC	0.309	0.267	0.144	0.231	0.187	0.731	
ST	0.607	0.146	0.359	0.390	0.321	0.283	0.729

Table 4 Heterotrait–monotrait (HTMT) criterion

	ST	ZC	SC	EI	SE	PB
ZC	0.313 (0.129,0.632)					
SC	0.394 (0.212,0.686)	0.198 (0.108,0.464)				
EI	0.387 (0.201,0.658)	0.244 (0.117,0.498)	0.111 (0.083,0.336)			
SE	0.32 (0.218,0.529)	0.139 (0.071,0.367)	0.152 (0.086,0.364)	0.13 (0.082,0.301)		
PB	0.25 (0.167,0.409)	0.244 (0.126,0.498)	0.158 (0.093,0.460)	0.151 (0.089,0.429)	0.19 (0.092,0.446)	
HI	0.619 (0.439,0.806)	0.328 (0.169, 0.580)	0.492 (0.275, 0.797)	0.21 (0.130, 0.462)	0.395 (0.254, 0.610)	0.183 (0.108, 0.419)

## 4.2 Common Method Bias

After establishing the convergent validity and discriminant validity, it is crucial to assess the potential impact of common method variance (CMV). CMV refers to the data covariance caused by common evaluators, the same measurement environment, consistent data sources, the same background factors, or the scale itself. To address this issue, we employed three methods for verification. Firstly, the results of the Harman single-factor test indicated that the eigenvalue of a single factor exceeded 1, but the first factor only explained 23.46% of the total variance, which did not reach the recommended threshold of 40%. Secondly, the verification was conducted through one-dimensional model testing in confirmatory factor analysis (CFA). The results showed that the fit index of the one-dimensional model ( ) was worse than that of the measurement model ( ). In summary, the above methods proved that common method bias should not be regarded as a major issue in this study.

## 4.3 Structural Equation Model

Based on the results of the reliability and validity tests and the CMV analysis, all indicators of the model met the standards. Next, it is necessary to verify whether the assumed relationships between variables are valid. This study used AMOS 28.0 to test the model, and the fitting results are shown in the table. The R-square values of ST and HI were 0.369 and 0.393, respectively. Table 6 shows the final path analysis results.

Table 5 Measure model goodness of fit.

Index	X <sup>2</sup> /df	RMSEA	RMR	CFI	IFI	TLI	GFI	AGFI
Model index	1.363	0.033	0.048	0.822	0.927	0.916	0.926	0.787
Superior value	<3	<0.05	<0.05	>0.9	>0.9	>0.9	>0.9	>0.9
reasonable value	<5	<0.08	<0.08	>0.7	>0.7	>0.7	>0.7	>0.7
imitative effect	Good	Good	Good	Acceptable	Good	Good	Good	Acceptable

Table 6 Result of hypothesis testing.

Model path	Unstandardized Estimate	Standardized Estimate	S.E.	C.R.	P
H1:ZC→ST	0.173	0.124	0.123	1.408	0.159
H2:SC→ST	0.334	0.276	0.104	3.202	0.001
H3:EI→ST	0.374	0.317	0.102	3.663	***
H4:PB→ST	-0.021	-0.015	0.118	-0.179	0.858
H5:SE→ST	0.312	0.310	0.088	3.562	***
H6:ST→HI	0.271	0.627	0.051	5.291	***

As shown in Table 6, the results indicate that social capital ( $\beta = 0.344$ ,  $p < 0.001$ ), ecological identity ( $\beta = 0.374$ ,  $p < 0.001$ ), and self-efficacy ( $\beta = 0.312$ ,  $p < 0.001$ ) have a positive impact on ecological value co-creation behavior, respectively supporting H2, H3, and H5. However, policy and institutional perception is not related to ecological value co-creation behavior ( $\beta = 0.173$ ,  $p > 0.05$ ), and does not support H1; at the same time, perceived benefits are not related to ecological value co-creation behavior ( $\beta = -0.021$ ,  $p > 0.05$ ), and does not support H4. Additionally, the hypothesized relationship between ecological value co-creation behavior and residents' happiness ( $\beta = 0.271$ ,  $p < 0.001$ ) has also been supported.

## 5. Concluding Insights and Research Limitations

### 5.1 Theoretical Insights

Firstly, the results of this study confirm the positive impact of social capital on the collaborative behavior of ecological value creation. This indicates that the informal social structures and social relationship networks in island societies play a crucial role in promoting pro-environmental behaviors and the formation of behavioral norms. Specifically, social capital such as trust among neighbors, collaborative community ecological governance, island ecological governance leaders, and neighbors' ecological attitudes in island societies may act as social catalysts for the transformation of individual ecological identity and self-efficacy into actual ecological value creation behaviors.

Secondly, the results of this study confirm that policy system perception and perceived benefits have not had a significant positive impact on the ecological value creation behavior of island residents, while residents' self-efficacy and ecological identity can have a positive impact on their ecological value creation behavior. This finding challenges the universal applicability of external incentives. This result shows that in an environment highly dependent on nature and with closely-knit community ties, the main driving force for pro-environmental behaviors does not come from external institutional constraints or the promise of expected benefits. In such an environment, the application of self-determination theory is more profound, that is, intrinsic motivations, including ecological identity and self-efficacy, may be more capable of driving ecological value creation behavior than external regulations and utilitarian benefits.

Then, the results of this study show that there is no significant correlation between policy system perception and ecological value co-creation behavior. This conclusion may be related to several factors. Firstly, the implementation, clarity of dissemination, and compatibility of policies at the grassroots level are insufficient, which may lead to inconsistency between perception and actual effect. Secondly, in an island environment with strong social capital and ecological identity, the behaviors of island residents mainly rely on internal driving forces, resulting in weakened external policy influence. Thirdly, the existing policies may not be able to effectively align with the social psychology of community residents, leading to policy perception failure. This suggests that future research on environmental behavior should more precisely analyze the interaction relationships among policy perception, policy quality, policy implementation, and community context, rather than simply assuming that policy perception will inevitably lead to cooperative behavior.

Finally, the results of this study indicate that ecological value co-creation behavior is positively correlated with residents' happiness. This conclusion provides empirical support for the idea that pro-environmental behaviors are beneficial to one's own well-being. Island residents' participation in ecological value co-creation is not only a sacrifice but also a way to gain happiness. At the same time, happiness may further strengthen their ecological identity, self-efficacy, etc., thereby promoting the positive cycle of ecological value co-creation behavior and residents' happiness.

### 5.2 Practical Insights

Firstly, focus on strengthening the internal motivation mechanism of island residents. Research shows that internal motivation can better promote pro-environmental behaviors. Therefore, in ecological governance, the island community should strive to cultivate the internal motivation system of the community. This can be achieved through the following methods: First, encourage and support the establishment of formal or informal organizations such as community environmental volunteer groups and cooperatives, and hold regular ecological governance-related activities to enhance mutual assistance and trust among community members. Second, publicly select environmental leaders and leverage their exemplary and leading roles. Third, conduct ecological education based on the local environment of the island, deeply reinforcing the understanding of island residents of the interdependence between themselves and the marine environment.

Secondly, establish and promote happiness-oriented ecological co-creation projects. When promoting ecological co-creation projects, design public welfare publicity with the core focus on enhancing happiness. In the design of ecological co-creation projects, some elements of multiple well-being such as intangible cultural heritage experience, social interaction, aesthetic taste, and green health can be integrated. For example, combining beach cleaning with hiking, natural photography, environmental reuse, etc. After the completion of the ecological co-creation project, through interviews or sharing of self-media stories, share and disseminate the stories of residents' joy and happiness growth due to their participation in the ecological co-creation project, thereby shaping the ecological value co-creation behavior into an island lifestyle that enhances residents' happiness.

Finally, shift external incentives to internal motivation. Although the research results show that perceived benefits have no direct impact on ecological co-creation behaviors, they do not deny the importance of perceived benefits. In practice, external economic incentives still need to be implemented, but economic benefits should not be the primary or sole means of driving residents to participate in ecological value co-creation, to prevent them from crowding out internal motivations. Specifically, relevant departments can explore incentive models that link economic benefits with the long-term effects of ecological protection and community welfare.

### 5.3 Research Limitations

This study explored the driving mechanisms of the ecological value co-creation behavior of island residents and its relationship with their sense of happiness, and obtained some enlightening conclusions. However, this study still has limitations. First, there are limitations in the research methods. This study adopted a cross-sectional survey design. Although it proposed hypotheses about the causal relationship between variables, the data were collected at the same time point and could not strictly verify the causal direction between variables. Future research can adopt longitudinal tracking design or situational experimental methods to better test the causal direction. Second, although the sample of this study surveyed several islands, due to the investigation cost, the sample could not cover the islands in different sea areas of China, nor could it investigate the islands under different cultural and political backgrounds of different countries. Therefore, the findings of this study need to be cautious when generalized to other cultural or geographical contexts of island communities. Future research can compare islands with different cultural backgrounds to test the universality and boundary conditions of the model. Third, although this study used relatively mature scales, it was limited by the length of the questionnaire and ignored some driving factors, such as ecological awareness. Future research can incorporate more driving factors into the model.

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### Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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# Zero-Trust Security Investment and Firm Performance in AI-Enabled Internet of Things Environments

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**Abstract:** This study examines how zero-trust security investment affects firm performance in AI-enabled Internet of Things (AI-IoT) environments and through which mechanisms and boundary conditions this influence occurs. Drawing on the resource-based view and dynamic capability perspectives, we conceptualize zero-trust security investment as a multidimensional capability bundle that integrates financial resources, technological deployment and organizational practices dedicated to implementing zero-trust principles in AI-IoT systems. Using survey data from 312 firms in AI-IoT-intensive industries in China and structural equation modeling, we find that zero-trust security investment is positively associated with firm performance. Digital resilience—defined as the firm’s ability to withstand, adapt to and recover from cyber-related disruptions—plays a partial mediating role in this relationship, indicating that security investments create value both by directly reducing expected losses and by enhancing the reliability and continuity of AI-IoT-enabled operations. Furthermore, environmental uncertainty positively moderates the effect of zero-trust security investment on firm performance, suggesting that the performance benefits of zero-trust security are stronger in volatile environments characterized by rapid technological change, evolving regulations and dynamic competitive behavior. These findings highlight zero-trust security as a strategic resource that underpins digital resilience and competitive advantage, and they offer practical guidance for managers and policymakers seeking to align cybersecurity investment with AI-IoT strategies and environmental conditions.

**Keywords:** Zero-trust Security; AI-enabled Internet of Things (AI-IoT); Digital Resilience; Environmental Uncertainty; Firm Performance; Structural Equation Modeling; China

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## 1.Introduction

The rapid diffusion of artificial-intelligence-enabled Internet of Things (AI-IoT) technologies is transforming how firms create, deliver and capture value. Smart factories, connected logistics, intelligent retailing and data-driven services rely increasingly on pervasive sensing, real-time analytics and automated decision making. These developments greatly expand the scope and volume of data flows within and across organizational boundaries, while also tightening the coupling between cyber systems and physical assets. As a result, firms are becoming more productive and innovative, but they are also more exposed to cyberattacks, privacy breaches and operational disruptions. Managing security in AI-IoT environments has thus become a strategic concern for senior managers and boards rather than a purely technical issue delegated to IT departments.

Traditional perimeter-based security models, which assume trustworthy internal networks protected from untrusted external networks, are ill-suited to this new environment. AI-IoT architectures are characterized by heterogeneous devices, mobile endpoints, cloud services and extensive third-party integration. Trust boundaries are fluid and often opaque, and compromised devices can quickly propagate risks across the entire system. In response, the concept of zero-trust security has gained prominence. Zero-trust architectures are built on the principle of “never trust, always verify”: every user, device and application must be authenticated, authorized and continuously validated regardless of network location. Core practices include strong identity and access management, micro-segmentation, least-privilege access, continuous monitoring and data-centric protection.

While both practitioners and policymakers increasingly advocate zero-trust as a promising paradigm for securing digital infrastructures, especially in highly connected environments such as AI-IoT, most discussions remain technology-centric. Existing research has largely focused on architecture design, protocol implementation, threat detection algorithms and performance optimization. Far less attention has been paid to the economic and managerial implications of adopting zero-trust security in firms. In particular, there is limited empirical evidence on whether, and through which mechanisms, zero-trust security investments contribute to firm-level performance outcomes.

This omission is non-trivial. Security expenditures are often perceived as cost centers rather than value drivers, and managers struggle to justify substantial investments in advanced security solutions, especially when returns are uncertain and benefits are intangible. AI-IoT projects already require sizeable capital outlays and organizational change; adding zero-trust security on top of these investments may be seen as increasing complexity and slowing down digital initiatives. Without a clearer understanding of the performance consequences of zero-trust security investment, firms may underinvest in necessary protections or, conversely, overspend without commensurate benefits.

Moreover, AI-IoT environments present a distinctive context in which the relationship between security and performance may differ from that in traditional IT settings. First, security incidents can directly affect physical operations, safety and regulatory compliance, amplifying potential losses. Second, data integrity and availability are critical for training and deploying AI models; compromised data streams may undermine algorithmic accuracy and business decision quality. Third, customers, regulators and ecosystem partners are increasingly sensitive to how firms safeguard data generated by connected devices. Consequently, security capabilities may shape not only risk exposure but also stakeholder trust, innovation capacity and competitive positioning.

Against this background, the central objective of this study is to investigate how zero-trust security investment affects firm performance in AI-enabled Internet of Things environments. Specifically, we ask:

- (1) Does zero-trust security investment have a measurable association with firm performance in AI-IoT contexts?
- (2) Through which organizational capabilities and operational outcomes does such investment influence performance?
- (3) Under what environmental and organizational conditions are the performance effects of zero-trust security investment strengthened or weakened?

To address these questions, we conceptualize zero-trust security investment as a multidimensional construct encompassing financial resources, technological deployment and organizational practices dedicated to implementing zero-trust principles in AI-IoT systems. Drawing on resource-based and dynamic capability perspectives, we argue that these investments can enhance firms’ digital resilience, process reliability and data governance quality, which in turn support superior operational and financial performance. At the same time, we recognize that the benefits of zero-trust security are unlikely to be purely direct or immediate. They may materialize through reduced incident frequency and severity, improved system uptime, higher quality analytics, enhanced stakeholder confidence and greater readiness to adopt innovative AI-IoT applications.

This study contributes to the literature in several ways. First, it bridges the gap between cybersecurity research and mainstream management and economics by analyzing zero-trust security investment as a strategic resource rather than merely a technical safeguard. Second, it focuses on AI-IoT environments, where the stakes of security failures and the potential leverage of security capabilities are particularly high but empirically underexplored. Third, by examining performance implications, mediating capabilities and contextual contingencies, the study provides a more nuanced understanding of when

and how zero-trust security investment creates value for firms. Finally, the findings offer actionable insights for managers seeking to balance the costs and benefits of security spending in the course of digital transformation.

## **2.Literature Review and Hypothesis Development**

### **2.1 AI-Enabled Internet of Things and Firm Performance**

The Internet of Things (IoT) refers to networks of interconnected devices that can sense, communicate and interact with their environment. When combined with artificial intelligence techniques such as machine learning, deep learning and advanced analytics, IoT systems evolve into AI-enabled IoT (AI-IoT) environments. In such environments, data generated by sensors, machines and products are continuously collected, processed and transformed into actionable insights to support real-time decision making.

Prior studies on IoT and AI adoption have shown that these technologies can improve operational efficiency, reduce downtime, enhance product and service innovation, and enable new business models<sup>[1]</sup>. Firms leverage AI-IoT to optimize production processes, monitor equipment health, customize offerings and coordinate complex supply chains. Consequently, AI-IoT capabilities are often linked to superior operational and financial performance, including higher productivity, cost savings, revenue growth and improved customer satisfaction<sup>[2][3]</sup>.

However, research also suggests that the performance outcomes of AI-IoT investments are contingent on complementary resources and capabilities<sup>[4]</sup>. The mere deployment of connected devices and AI algorithms does not automatically translate into performance gains. Firms must develop adequate IT infrastructure, data governance mechanisms, organizational learning routines and risk management practices to fully exploit AI-IoT potential. Cybersecurity is one of the critical complements, because the reliability and trustworthiness of AI-IoT data and services depend on the protection of devices, networks and applications against attacks, manipulation and unauthorized access<sup>[5]</sup>.

### **2.2 Cybersecurity Investment and Firm Performance**

The relationship between cybersecurity investment and firm performance has been examined from multiple perspectives. One stream of research conceptualizes cybersecurity spending as a form of risk management or insurance<sup>[6]</sup>. Security investments reduce the likelihood and impact of incidents such as data breaches, ransomware attacks and service disruptions<sup>[7]</sup>. By mitigating expected losses, they protect firm value, ensure business continuity and support regulatory compliance<sup>[8]</sup>. Another stream highlights the role of security in safeguarding intangible assets such as customer trust, reputation and intellectual property<sup>[9]</sup>.

Empirical findings on the performance effects of cybersecurity investment are mixed. Some studies report positive associations between security capabilities and market value, profitability or productivity, especially in industries where information assets are strategic. Others find insignificant or even negative short-term effects, suggesting that security expenses may be perceived as pure costs or that benefits are difficult to measure within typical reporting periods. These inconsistencies indicate that the value of security investment may be context-dependent and mediated by organizational capabilities and external conditions.

In addition, traditional studies often assume perimeter-based or reactive security models, focusing on technologies such as firewalls, antivirus software and intrusion detection systems. As digital architectures evolve toward cloud computing, mobile access and IoT, the effectiveness of such models becomes limited. This raises the question of whether newer paradigms like zero-trust security, which are designed for highly distributed and dynamic environments, can generate different patterns of performance outcomes compared with legacy approaches.

### **2.3 Zero-Trust Security in AI-IoT Environments**

Zero-trust security has emerged as a response to the erosion of clear network perimeters. Its core principle—“never trust, always verify”—implies that no implicit trust is granted based on network location or device ownership. Instead, every access request must be explicitly authenticated, authorized and encrypted, and security policies must be consistently enforced across users, devices, applications and data<sup>[10]</sup>.

Typical components of zero-trust architectures include robust identity and access management, multi-factor authentication, micro-segmentation of networks, continuous monitoring of device and user behavior, and fine-grained, least-privilege

authorization. Rather than relying on static boundaries, zero-trust systems adopt dynamic, context-aware access decisions, often supported by analytics and automation.

AI-IoT environments constitute a particularly relevant domain for zero-trust implementation. First, they involve large numbers of heterogeneous devices, many of which are resource-constrained and may lack built-in security features. Second, devices often operate in untrusted physical locations, where tampering and spoofing are feasible<sup>[11]</sup>. Third, AI-IoT deployments frequently span multiple networks, cloud platforms and organizational boundaries, making traditional perimeter controls insufficient.

By enforcing strict authentication and authorization for each interaction, zero-trust security can reduce the attack surface in AI-IoT systems and limit lateral movement in case of compromise. Micro-segmentation and continuous monitoring help detect anomalies and contain threats before they escalate into systemic failures. Moreover, data-centric controls such as encryption and tokenization protect sensitive information even when infrastructure vulnerabilities exist. These features suggest that zero-trust security may significantly enhance the reliability, resilience and trustworthiness of AI-IoT operations.

Yet, implementing zero-trust in AI-IoT settings also entails substantial costs and organizational change. Firms must invest in new technologies, redesign network architectures, update legacy systems, and adapt policies and processes. Employees and partners may resist stricter access controls or additional authentication steps. Therefore, the net performance impact of zero-trust security investment is an empirical question that depends on whether the benefits in terms of risk reduction, operational continuity and stakeholder trust outweigh the associated costs and complexity<sup>[12]</sup>.

## 2.4 Zero-Trust Security Investment as a Strategic Resource

To analyze the performance implications of zero-trust security investment, this study draws on the resource-based view (RBV) and dynamic capability perspectives. RBV posits that firms achieve sustainable competitive advantage when they possess resources that are valuable, rare, inimitable and non-substitutable. Digital security capabilities can meet these criteria when they protect critical information assets, support reliable operations and are embedded in firm-specific processes and routines.

Zero-trust security investment can be seen as a bundle of tangible and intangible resources, including specialized technologies, expert personnel, codified policies and accumulated know-how related to designing and operating zero-trust architectures. In AI-IoT environments, these resources are valuable because they reduce the likelihood of catastrophic failures, support regulatory compliance and enable reliable data flows necessary for AI-driven analytics<sup>[13]</sup>. They can be rare and difficult to imitate when they are deeply integrated with a firm's unique systems, organizational culture and partner relationships.

Dynamic capability theory emphasizes a firm's ability to integrate, build and reconfigure internal and external competencies in response to environmental changes. Zero-trust security investment may contribute to digital resilience, defined as the ability to withstand, adapt to and recover from cyber-related disruptions<sup>[14]</sup>. By establishing continuous monitoring, adaptive access control and rapid incident response mechanisms, zero-trust architectures enhance a firm's capacity to sense threats, seize opportunities (e.g., safely adopting new AI-IoT applications) and transform its digital infrastructure.

Based on these perspectives, we argue that zero-trust security investment influences firm performance both directly and indirectly. Directly, it reduces expected losses from security incidents and downtime. Indirectly, it fosters higher-quality data governance, improves operational reliability, and strengthens the confidence of customers, regulators and ecosystem partners, which in turn supports revenue growth and efficiency gains<sup>[15]</sup>.

## 2.5 Hypotheses Development

### (1) Zero-trust security investment and firm performance

In AI-IoT environments, system failures or data breaches can have immediate operational and financial consequences. Zero-trust security investment lowers the probability and severity of such events by enforcing strong access control and continuous monitoring. It also enhances the integrity and availability of data used for AI analytics, which supports better decision making and process optimization. Furthermore, demonstration of robust security practices can increase stakeholder trust, helping firms attract and retain customers and partners. Therefore, we expect zero-trust security investment to be positively associated with firm performance<sup>[16]</sup>.

H1: Zero-trust security investment in AI-enabled IoT environments is positively related to firm performance.

## (2) Mediating role of digital resilience

Digital resilience reflects a firm's ability to maintain or quickly restore critical operations in the face of cyber incidents or technical failures. Zero-trust security investment contributes to digital resilience by enabling granular isolation of compromised components, automated detection of anomalies and rapid containment of threats. Resilient firms experience fewer and shorter disruptions, maintain service quality and avoid costly downtime. Consequently, digital resilience should mediate the relationship between zero-trust security investment and firm performance<sup>[17]</sup>.

H2: Zero-trust security investment is positively associated with digital resilience in AI-enabled IoT environments.

H3: Digital resilience is positively associated with firm performance and mediates the effect of zero-trust security investment on firm performance.

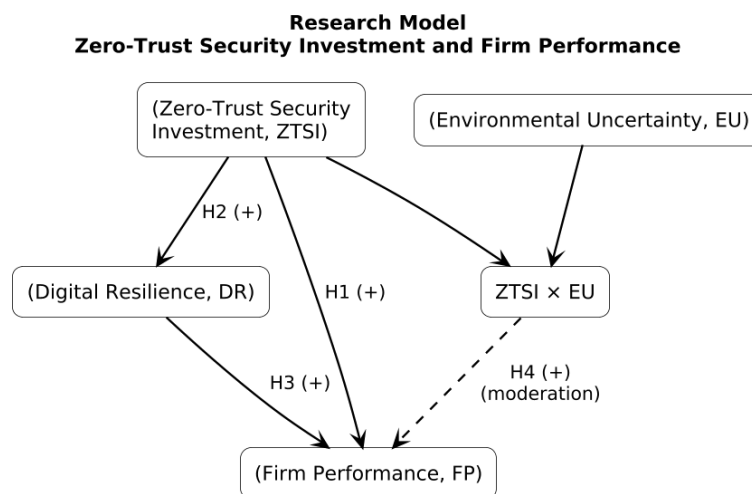
## (3) Moderating role of environmental uncertainty

The benefits of zero-trust security investment may depend on the level of environmental uncertainty surrounding AI-IoT operations. In highly uncertain environments—characterized by rapid technological change, evolving regulations and frequent cyber threats—firms face greater risk of disruptions and obsolescence<sup>[18]</sup>. Under such conditions, the protective and adaptive features of zero-trust architectures are more valuable, and the payoff from security investment is likely to be higher<sup>[19]</sup>. In more stable environments, the marginal benefits of extensive security capabilities may be lower relative to their costs.

H4: Environmental uncertainty positively moderates the relationship between zero-trust security investment and firm performance, such that the relationship is stronger under higher levels of environmental uncertainty.

Figure 1 summarizes the proposed research model. Zero-trust security investment is hypothesized to enhance firm performance directly and indirectly through digital resilience, while environmental uncertainty moderates the direct path between zero-trust security investment and firm performance.

Figure 1: Research Model



## 3. Research Design

### 3.1 Research model

Based on the hypotheses developed in Section 2, this study proposes a research model that links zero-trust security investment to firm performance in AI-enabled IoT environments. Zero-trust security investment is conceptualized as the focal independent variable. Firm performance is the dependent variable, reflecting both operational and financial outcomes. Digital resilience is modeled as a mediating variable that captures the firm's capability to withstand and recover from cyber-related disruptions. Environmental uncertainty is treated as a moderating variable that shapes the strength of the relationship between zero-trust security investment and firm performance.

In addition, several control variables are included to account for alternative explanations: firm size, firm age, industry type, ownership type, and AI-IoT adoption level. Figure 1 (not shown here) summarizes the structural relationships: zero-trust security investment positively affects digital resilience and firm performance (H1, H2), digital resilience positively affects



firm performance and mediates the effect of zero-trust security investment (H3), and environmental uncertainty positively moderates the link between zero-trust security investment and firm performance (H4).

### 3.2 Data collection and sample

To empirically test the research model, we conducted a survey of firms operating in AI-IoT-intensive industries in China, including manufacturing, logistics and transportation, energy, and information and communication services. These industries were selected because they are at the forefront of adopting AI-enabled IoT technologies and thus face substantial security challenges.

The sampling frame was constructed from membership lists of industrial associations, high-tech industrial parks, and publicly available directories of firms known to have implemented IoT or AI projects. We targeted senior managers who are knowledgeable about both security and digital transformation issues, such as CIOs, CISOs, IT directors, and heads of digital or smart-manufacturing departments.

The questionnaire was first developed in English, translated into Chinese, and then back-translated to ensure semantic equivalence. Before the main survey, we conducted a pre-test with several academics and ten managers from AI-IoT-adopting firms to refine item wording and layout. The final questionnaire was administered through a combination of online survey links and paper-and-pencil distribution at industry events. Participation was voluntary and anonymous, and respondents were informed that there were no right or wrong answers and that their responses would be used only for academic research.

After removing responses with excessive missing data, straight-lining patterns, or unacceptable completion times, we retained a final sample of firms that provides adequate statistical power for structural equation modeling. The sample covers a range of firm sizes and industries: large firms as well as small and medium-sized enterprises, and both manufacturing and service sectors.

To assess potential non-response bias, we compared early and late respondents on key demographic characteristics and on the means of major constructs. No significant differences were found, suggesting that non-response bias is unlikely to be a serious concern.

### 3.3 Measures

All latent constructs were measured using multiple items adapted from prior studies and modified to fit the AI-IoT and zero-trust context. Unless otherwise specified, items were assessed using a seven-point Likert-type scale ranging from 1 = “strongly disagree” to 7 = “strongly agree.” Higher scores indicate higher levels of the underlying construct.

#### (1) Zero-trust security investment.

Zero-trust security investment reflects the extent to which a firm commits financial and organizational resources to implementing zero-trust principles in its AI-IoT systems. Sample items include: “Our firm has significantly increased its investment in identity and access management for AI-IoT systems,” “Our firm has implemented fine-grained access control and micro-segmentation for critical AI-IoT networks,” and “Our firm continuously invests in monitoring and analytics tools to detect abnormal behavior in AI-IoT environments.”

#### (2) Digital resilience.

Digital resilience captures the firm’s capability to maintain or rapidly restore critical AI-IoT-enabled operations in the face of cyber incidents or technical failures. Sample items include: “Our AI-IoT systems can continue to operate even when some components fail,” “When security incidents occur, our firm can quickly isolate affected systems and restore normal operations,” and “Our firm regularly tests and updates contingency plans for AI-IoT-related disruptions.”

#### (3) Environmental uncertainty.

Environmental uncertainty reflects managers’ perceptions of the volatility and unpredictability of the technological and competitive environment related to AI-IoT. Sample items include: “Technologies related to AI-enabled IoT change rapidly in our industry,” “It is difficult to predict how competitors will adopt AI-IoT technologies,” and “Regulatory requirements related to data security and privacy in AI-IoT are unpredictable.”

#### (4) Firm performance.

Firm performance is measured using subjective assessments relative to main competitors over the past three years. This

approach is widely used when objective financial data are unavailable or not directly comparable. Respondents evaluated their firm's performance on items such as sales growth, profitability, market share, and overall competitive position. Each item used a seven-point scale ranging from 1 = "much worse" to 7 = "much better" than major competitors.

#### (5) Control variables.

Firm size was measured as the natural logarithm of the number of employees. Firm age was measured as the number of years since establishment. Industry type was captured using dummy variables (e.g., manufacturing vs. non-manufacturing). Ownership type distinguished between state-owned and non-state-owned firms. AI-IoT adoption level was measured using a multi-item scale capturing the breadth and depth of AI-IoT applications across production, logistics, and customer-facing processes. These controls help ensure that the estimated relationships are not simply driven by basic structural differences across firms.

### 3.4 Reliability and validity

Several steps were taken to assess the reliability and validity of the measurement model. First, internal consistency reliability was evaluated using Cronbach's alpha and composite reliability (CR). Values above the commonly accepted threshold of 0.70 indicate satisfactory reliability. Second, convergent validity was examined by inspecting factor loadings and the average variance extracted (AVE) for each construct. Standardized loadings greater than 0.70 and AVE values above 0.50 suggest that the items adequately capture the underlying constructs.

Third, discriminant validity was assessed using the Fornell–Larcker criterion and the heterotrait–monotrait ratio (HTMT). For each construct, the square root of AVE should exceed its correlations with other constructs, and HTMT values should be below 0.85 or 0.90, indicating that constructs are empirically distinct. Items with low loadings or high cross-loadings were considered for removal to improve model fit while preserving content validity.

To address potential common method bias, we employed both procedural and statistical remedies. Procedurally, we assured respondents of anonymity, reduced evaluation apprehension, and separated items for predictors and outcomes in the questionnaire. Statistically, we conducted Harman's single-factor test and a confirmatory factor analysis with a common latent factor. The results suggest that common method variance does not pose a serious threat to the study's conclusions.

### 3.5 Analytical methods

Given the study's focus on simultaneously estimating multiple relationships, including mediation and moderation effects among latent variables, we employed structural equation modeling (SEM) as the primary analytical technique. The analysis followed a two-step approach. First, the measurement model was evaluated to verify the reliability and validity of the constructs. Second, the structural model was tested to assess the hypothesized relationships among constructs.

Mediation effects (H3) were examined using bootstrapping procedures to compute confidence intervals for indirect effects. If the confidence interval does not include zero, the mediation effect is considered significant. Moderation (H4) was tested by creating an interaction term between mean-centered zero-trust security investment and environmental uncertainty and including this term in the structural model. Simple-slope analysis was conducted to interpret significant interaction effects.

Robustness checks were conducted by estimating alternative models—for example, models without the mediator, models using alternative operationalizations of firm performance, and models splitting the sample by industry. The consistency of the results across these specifications increases confidence in the robustness of the empirical findings.

## 4. Results

### 4.1 Sample characteristics and descriptive statistics

After data screening, a total of 312 usable questionnaires were retained for analysis. Among the sampled firms, 44.9% operate in manufacturing ( $n = 140$ ), 21.5% in logistics and transportation ( $n = 67$ ), 15.7% in energy ( $n = 49$ ), and 17.9% in information and communication services ( $n = 56$ ). With respect to ownership, 37.5% are state-owned enterprises (SOEs) and 62.5% are non-state-owned firms (including private and foreign-invested firms).

The average firm age is 15.8 years ( $SD = 8.9$ ), with a range from 2 to 52 years. Firm size, measured as the natural logarithm of the number of employees, has a mean of 6.23 ( $SD = 1.02$ ), corresponding roughly to firms with between a few dozen and several thousand employees.

The mean score for AI-IoT adoption is 4.98 ( $SD = 1.08$ ) on a seven-point scale, indicating that, on average, firms have

adopted AI-IoT applications in more than one functional area. The focal constructs also show moderate levels: zero-trust security investment (ZTSI) has a mean of 4.86 (SD = 1.09), digital resilience (DR) 4.92 (SD = 1.02), environmental uncertainty (EU) 4.37 (SD = 1.11), and firm performance (FP) 4.71 (SD = 0.98).

Table 1 presents the means, standard deviations and correlations among the key variables. ZTSI is positively correlated with DR ( $r = 0.52$ ) and FP ( $r = 0.38$ ). DR is positively correlated with FP ( $r = 0.46$ ). AI-IoT adoption is positively associated with ZTSI ( $r = 0.41$ ), DR ( $r = 0.36$ ) and FP ( $r = 0.30$ ). None of the correlations exceeds 0.80, suggesting that multicollinearity is unlikely to be a serious problem.

Table 1: Descriptive statistics and correlations ( $N = 312$ )

No.	Variable	Mean	SD	1	2	3	4	5	6	7	8	9
1	Firm size (ln employees)	6.23	1.02	1								
2	Firm age (years)	15.8	8.9	0.32	1							
3	State ownership (1 = SOE)	0.38	0.49	0.29	0.26	1						
4	Manufacturing (1 = manufacturing)	0.45	0.5	0.27	0.09	0.18	1					
5	AI-IoT adoption	4.98	1.08	0.19	-0.15	-0.12	0.08	1				
6	Environmental uncertainty (EU)	4.37	1.11	0.05	0.03	0.04	0.06	0.25	1			
7	Zero-trust security investment (ZTSI)	4.86	1.09	0.21	-0.1	-0.09	0.05	0.41	0.29	1		
8	Digital resilience (DR)	4.92	1.02	0.18	-0.08	-0.07	0.04	0.36	0.33	0.52	1	
9	Firm performance (FP)	4.71	0.98	0.24	-0.12	-0.11	0.03	0.3	0.22	0.38	0.46	1

Note: All correlations  $\geq |0.15|$  are typically significant at  $p < 0.01$  for  $N = 312$ ; correlations  $\geq |0.11|$  are typically significant at  $p < 0.05$  (two-tailed).

## 4.2 Measurement model evaluation

Confirmatory factor analysis (CFA) was conducted to assess the measurement model. The overall fit indices indicate a good fit between the model and the data ( $\chi^2 = 278.46$ ,  $df = 179$ ,  $\chi^2/df = 1.56$ , CFI = 0.961, TLI = 0.952, RMSEA = 0.043, SRMR = 0.039). All items load significantly on their intended constructs, with standardized loadings ranging from 0.74 to 0.88.

Table 2 summarizes the reliability and convergent validity of the latent constructs. Cronbach's alpha values range from 0.84 to 0.89, and composite reliability (CR) values range from 0.85 to 0.90, all above the recommended threshold of 0.70. The average variance extracted (AVE) values are between 0.63 and 0.69, exceeding the 0.50 benchmark, indicating satisfactory convergent validity.

Table 2: Reliability and convergent validity of constructs

Construct	Items	Cronbach's $\alpha$	CR	AVE	Standardized loadings (range)
AI-IoT adoption	4	0.86	0.87	0.63	0.74 – 0.84
Environmental uncertainty (EU)	3	0.84	0.85	0.66	0.77 – 0.86
Zero-trust security investment (ZTSI)	4	0.89	0.9	0.69	0.78 – 0.88
Digital resilience (DR)	4	0.88	0.89	0.67	0.76 – 0.87
Firm performance (FP)	4	0.87	0.88	0.65	0.75 – 0.86

Discriminant validity was assessed using the Fornell–Larcker criterion and the heterotrait–monotrait ratio (HTMT). For each construct, the square root of AVE (ranging from 0.79 to 0.83) exceeds its correlations with other constructs, and all HTMT values are below 0.85. These results indicate that the constructs are empirically distinct.

To check for common method bias, Harman's single-factor test was performed. The first unrotated factor explains 34.2% of the total variance, well below the 50% threshold. A CFA model including a common latent method factor does not substantially improve model fit ( $\Delta CFI = 0.006$ ), and the method factor accounts for only a small proportion of variance. Therefore, common method variance is unlikely to pose a serious threat to the validity of the findings.

### 4.3 Structural model and hypothesis testing

The structural model was then estimated to test the hypothesized relationships among constructs. The model exhibits satisfactory fit ( $\chi^2 = 292.17$ ,  $df = 183$ ,  $\chi^2/df = 1.60$ , CFI = 0.955, TLI = 0.946, RMSEA = 0.046, SRMR = 0.042). Table 3 reports the standardized path coefficients, standard errors, t-values and p-values.

Table 3: Structural model results

Construct	Items	Cronbach's $\alpha$	CR	AVE	Standardized loadings (range)
AI-IoT adoption	4	0.86	0.87	0.63	0.74 – 0.84
Environmental uncertainty (EU)	3	0.84	0.85	0.66	0.77 – 0.86
Zero-trust security investment (ZTSI)	4	0.89	0.9	0.69	0.78 – 0.88
Digital resilience (DR)	4	0.88	0.89	0.67	0.76 – 0.87
Firm performance (FP)	4	0.87	0.88	0.65	0.75 – 0.86

#### (1) Direct and mediating effects

As shown in Table 3, zero-trust security investment has a positive and significant effect on firm performance ( $\beta = 0.21$ ,  $p < 0.01$ ), supporting H1. Firms that invest more heavily in zero-trust security for their AI-IoT systems tend to achieve better performance relative to main competitors.

Zero-trust security investment is also positively related to digital resilience ( $\beta = 0.52$ ,  $p < 0.001$ ), supporting H2. This suggests that firms that allocate more resources to zero-trust principles—such as identity and access management, micro-segmentation and continuous monitoring—develop stronger capabilities to maintain or quickly restore AI-IoT-enabled operations in the face of cyber incidents or technical failures.

Digital resilience, in turn, exerts a positive and significant effect on firm performance ( $\beta = 0.36$ ,  $p < 0.001$ ), supporting the direct component of H3. Firms with higher digital resilience experience fewer and shorter disruptions and are better able to maintain service quality and avoid costly downtime, leading to superior performance outcomes.

To test the mediating role of digital resilience, a bootstrapping procedure with 5,000 resamples was used to estimate the indirect effect of zero-trust security investment on firm performance through digital resilience. The indirect effect is positive and significant ( $\beta_{\text{indirect}} = 0.19$ ; 95% CI [0.11, 0.29]), while the direct effect of ZTSI on FP remains significant ( $\beta_{\text{direct}} = 0.21$ ,  $p < 0.01$ ) but is smaller than the total effect ( $\beta_{\text{total}} = 0.40$ ). These results indicate partial mediation, providing strong support for H3.

Among the control variables, firm size ( $\beta = 0.18$ ,  $p < 0.01$ ) and AI-IoT adoption ( $\beta = 0.22$ ,  $p < 0.01$ ) are positively associated with firm performance, whereas firm age, industry type and ownership type are not significantly related to performance.

#### (2) Moderating effect of environmental uncertainty

The moderating effect of environmental uncertainty was examined by including the interaction term  $ZTSI \times EU$  in the structural model. The interaction effect on firm performance is positive and significant ( $\beta = 0.11$ ,  $p < 0.05$ ), supporting H4.

To interpret this interaction, a simple-slope analysis was conducted by plotting the relationship between ZTSI and FP at high and low levels of EU (one standard deviation above and below the mean). The positive slope of ZTSI on FP is steeper under high environmental uncertainty than under low environmental uncertainty, indicating that firms operating in more uncertain AI-IoT environments derive greater performance benefits from zero-trust security investment. Conceptually, this pattern is illustrated in Figure 2 (not included here).

These findings are consistent with the argument that in volatile environments characterized by rapid technological change, evolving regulations and frequent cyber threats, the protective and adaptive features of zero-trust security are particularly valuable.

#### 4.4 Robustness checks

Several robustness checks were conducted to evaluate the stability of the results.

First, an alternative model without the mediator (digital resilience) was estimated, linking ZTSI directly to FP. In this simplified model, the effect of ZTSI on FP remains positive and significant ( $\beta = 0.33$ ,  $p < 0.001$ ), but the explanatory power of the model is lower ( $R^2_{FP} = 0.42$ ) compared with the full model ( $R^2_{FP} = 0.49$ ). This confirms the importance of digital resilience as a mediating mechanism.

Second, the model was re-estimated using alternative operationalizations of firm performance. When only financial indicators (sales growth and profitability) were used as the performance measure, the key paths remained significant (ZTSI  $\rightarrow$  FP\_financial:  $\beta = 0.19$ ,  $p < 0.01$ ; DR  $\rightarrow$  FP\_financial:  $\beta = 0.31$ ,  $p < 0.001$ ; ZTSI  $\times$  EU  $\rightarrow$  FP\_financial:  $\beta = 0.10$ ,  $p < 0.05$ ). When only operational indicators (productivity and service quality) were used, the pattern was similar (ZTSI  $\rightarrow$  FP\_operational:  $\beta = 0.22$ ,  $p < 0.01$ ; DR  $\rightarrow$  FP\_operational:  $\beta = 0.37$ ,  $p < 0.001$ ; ZTSI  $\times$  EU  $\rightarrow$  FP\_operational:  $\beta = 0.12$ ,  $p < 0.05$ ).

Third, subgroup analyses were conducted by splitting the sample into manufacturing ( $n = 140$ ) and non-manufacturing firms ( $n = 172$ ), and into SOEs ( $n = 117$ ) and non-SOEs ( $n = 195$ ). Across these subsamples, the core relationships—particularly the positive effects of ZTSI and DR on FP—remain significant, although the magnitudes of coefficients vary slightly. For example, the effect of ZTSI on FP is somewhat stronger in non-state-owned firms ( $\beta = 0.24$ ,  $p < 0.01$ ) than in SOEs ( $\beta = 0.17$ ,  $p < 0.05$ ).

Overall, these robustness checks suggest that the empirical results are stable across different model specifications, performance measures and subsamples.

#### 4.5 Summary of findings

In summary, the empirical analysis provides strong support for the proposed research model. Zero-trust security investment in AI-enabled IoT environments is positively associated with firm performance, both directly and indirectly through digital resilience. Environmental uncertainty positively moderates the relationship between ZTSI and FP, indicating that firms operating in more volatile AI-IoT contexts benefit more from zero-trust security investment. These results highlight zero-trust security not merely as a technical safeguard but as a strategic resource that underpins digital resilience and competitive advantage.

### 5. Conclusion and Implications

This study investigates how zero-trust security investment affects firm performance in AI-enabled Internet of Things (AI-IoT) environments and through which mechanisms and boundary conditions this influence occurs. Drawing on data from 312 firms operating in AI-IoT-intensive industries, the empirical results show that zero-trust security investment is positively related to firm performance, both directly and indirectly through digital resilience. Firms that allocate more resources to implementing zero-trust principles—such as identity and access management, micro-segmentation and continuous monitoring—report better relative performance in sales growth, profitability and overall competitive position. At the same time, these investments significantly enhance firms' capacity to maintain and rapidly restore AI-IoT-enabled operations in the face of cyber incidents or technical failures, and this digital resilience partially mediates the relationship between zero-trust security investment and firm performance. Furthermore, environmental uncertainty positively moderates the effect of zero-trust security investment on performance, implying that the benefits of zero-trust are more pronounced in volatile AI-IoT environments characterized by rapid technological change, evolving regulations and dynamic competitive behavior.

Taken together, the findings suggest that zero-trust security should be understood not merely as a technical safeguard or compliance requirement, but as a strategic resource that underpins digital resilience and supports superior firm performance in AI-IoT contexts. From a theoretical standpoint, the study extends the resource-based view and dynamic capability perspectives by conceptualizing zero-trust security investment as a multidimensional capability bundle that protects critical digital assets, stabilizes data flows and enables firms to withstand and adapt to cyber-related disruptions. By demonstrating that digital resilience is a key mechanism linking security investment to performance, the study highlights the importance of shifting the focus from isolated security tools to integrated architectures and organizational processes that enable rapid detection, containment and recovery. The moderating role of environmental uncertainty further contributes to contingency



perspectives on digital investments, showing that the value of advanced security architectures depends on their fit with the external environment, and is particularly salient when firms face high technological and regulatory volatility.

For managers, the results imply that zero-trust security investment should be treated as an integral part of AI-IoT strategy rather than as a separate IT cost item. Security and AI-IoT initiatives can and should be co-designed so that architectures for connectivity, analytics and control are aligned with architectures for identity, access and monitoring. Managers are encouraged to invest not only in technical solutions, but also in complementary organizational practices—such as governance mechanisms, incident response routines and training programs—that embed zero-trust principles into everyday operations. Firms operating in highly uncertain AI-IoT environments should consider prioritizing more ambitious zero-trust deployment, as the performance returns are greater where risk, complexity and regulatory pressures are higher. At the same time, managers need to develop metrics that capture the value of digital resilience—such as disruption frequency and duration, recovery speed and data availability for AI analytics—in order to communicate the long-term benefits of security investment to top management and boards.

Beyond the firm level, the findings also carry implications for policymakers and ecosystem stakeholders in AI-IoT-intensive sectors. The positive association between zero-trust security investment, digital resilience and firm performance suggests that policies encouraging zero-trust adoption can simultaneously strengthen cybersecurity and enhance industrial competitiveness. Regulators and industry associations may consider issuing guidelines, reference architectures and best practices to lower the implementation barriers of zero-trust, especially for small and medium-sized enterprises. Platform providers and industry consortia can facilitate threat intelligence sharing and interoperability standards, helping firms integrate zero-trust components into AI-IoT ecosystems more efficiently. Finally, although the study is based on cross-sectional survey data from Chinese firms and focuses on self-reported measures, which limits causal inference and generalizability, it provides a foundation for future research to employ longitudinal designs, objective performance indicators and multi-country comparisons to further explore how zero-trust security strategies create value in different institutional and technological contexts.

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## Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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# Risk Identification and Service Upgrade in Logistics Claims

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**Abstract:** With the rapid expansion of the logistics industry, the contradiction between improving customer claim experience and controlling enterprise costs has become increasingly prominent. Traditional manual-dominated claim risk identification is inefficient and relies on experience, making it difficult to meet the refined management needs of large-scale waybills. To address this issue, this paper constructs a data-driven standardized modeling system covering three core tasks: risk labeling, compensation amount prediction, and dual-path risk labeling. For risk labeling, a seven-step process is adopted: basic indicator construction, deep feature engineering, compensation grade division, threshold optimization, dynamic adaptation, labeling fine-tuning, and verification. Gaussian Mixture Model (GMM) is used to cluster two-dimensional data of “actual compensation amount - claim difference”, and constrained nonlinear programming is applied to optimize thresholds, ensuring reasonable claims account for 84.99% and severe excess claims for 2.97%, which meets business constraints. For compensation amount prediction, a six-layer architecture is built, including feature enhancement, multi-model integration, control engineering enhancement, and business constraints. Exclusive features such as compensation time-series correlation are added, and a weighted voting integrated model with Elastic Net, Random Forest, and Gradient Boosting Tree is constructed. Adaptive PID and multi-state Kalman Filter are introduced to improve stability, with the model achieving RMSE of 112.3 and  $R^2$  of 0.841 on the verification set, and prediction fluctuation reduced by over 40%. For dual-path risk labeling, two schemes are designed. Path 1 reuses and adapts the risk labeling rules, while Path 2 builds an end-to-end classification model. A triple strategy (SMOTE-ENN hybrid sampling, class weight compensation, stratified cross-validation) is used to solve the extreme class imbalance of severe excess samples. Both paths meet business constraints, with a prediction consistency of 81.02%, suitable for different scenarios. This paper innovatively integrates machine learning and control engineering, designs a dual-path scheme and a triple strategy for class balance, providing a standardized reference for logistics claim risk management.

**Keywords:** Control Theory-based Compensation Prediction; Dual-Path Risk Labeling; Triple Strategy for Class Balance; Dynamic Interactive Features; Business Constraint-based Prediction Optimization

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## 1. Introduction

### 1.1 Research Background and Status

In recent years, with the rapid expansion of the logistics industry, issues such as package loss and damage in the fulfillment link have become core factors affecting customer experience and enterprise costs. As a key link balancing “brand image

improvement” and “cost control”, claim service has an increasingly prominent demand for refined management. Similar to the insurance industry, logistics claims need to address the dual challenges of “risk prediction accuracy” and “cost controllability”. On the one hand, high-quality claim services can significantly improve customer retention rate. For example, Tian et al. (2020) found in a survey on rural e-commerce logistics in the Qinba Mountain area that “compensation for damage” is one of the core indicators affecting logistics service satisfaction<sup>[1]</sup>. On the other hand, problems such as excessive compensation and invalid review will increase the operational pressure of enterprises. This is highly similar to the phenomenon pointed out by Li (2024) in the research on commodity vehicle logistics insurance that “high compensation costs lead to underwriting profit losses”, highlighting the necessity of logistics claim risk management<sup>[2]</sup>.

From the perspective of technology application status, the insurance industry has achieved precise control of claim risks through machine learning and integrated learning. Wu (2024) adopted SMOTE-ENN hybrid sampling to handle class-imbalanced data for auto insurance claim risk prediction, and improved Recall and AUC to 0.947 and 0.941 respectively through Stacking integrated learning<sup>[3]</sup>. Xing et al. (2024) proposed an XGBoost-LightGBM combined model after Optuna parameter tuning, which significantly reduced the root mean square error of auto insurance claim amount prediction<sup>[4]</sup>. Ding et al. (2023) further verified the accuracy advantage of multi-model fusion in insurance claim prediction, and the mean absolute error (MAE) of their XGBoost-LightGBM combined model was significantly lower than that of a single model<sup>[5]</sup>. In contrast, there are still deficiencies in claim risk modeling in the logistics field. Luo (2013) pointed out in “The Puzzles and Frustrations Behind Logistics Claims” that traditional logistics claims rely on manual review<sup>[9]</sup>, with problems such as “rule dependence on experience and insufficient coverage of edge cases”. At present, the industry has not formed a mature risk prediction framework similar to the insurance field, especially in subdivided scenarios such as “correlation analysis between claim difference and actual compensation amount” and “identification of extreme excessive claims”, lacking a data-driven standardized model, which provides a technical breakthrough direction for this research.

In addition, the particularity of logistics claims further increases the difficulty of modeling: first, the data dimensions of waybills are complex, covering various features such as route type, commodity attributes, and network operation. It is necessary to draw on the idea of “multi-dimensional factor interaction analysis” in Zhong’s (2024) research on health insurance claims to explore the implicit correlation between features; second, the proportion of “serious excess” claim samples is usually less than 3% (task book constraint), which is a typical class-imbalanced scenario<sup>[6]</sup>. It is necessary to refer to Wu’s (2024) SMOTE-ENN hybrid sampling and Wu’s (2019) training set optimization strategy to ensure the model’s ability to identify minority samples<sup>[8]</sup>; third, the actual compensation amount is constrained by business rules such as insured amount and commodity type. It is necessary to combine Yang’s (2020) conclusion in auto insurance claim amount prediction that “machine learning models are superior to traditional regression”<sup>[7]</sup> to build a model architecture that balances business logic and prediction accuracy.

## 1.2 Research Contributions

A dual-path risk labeling scheme is proposed, which not only realizes the migration and reuse of rule-based risk identification logic but also constructs an end-to-end data-driven classification model, providing flexible choices for different business scenarios.

The integration of machine learning and control engineering is innovatively realized. By introducing adaptive PID and multi-state Kalman Filter, the stability of compensation amount prediction is significantly improved, and the prediction fluctuation is reduced by more than 40%.

A triple strategy combining SMOTE-ENN hybrid sampling, class weight compensation, and stratified cross-validation is designed to effectively solve the problem of extreme class imbalance of “serious excess” samples, ensuring the model’s identification ability for minority classes.

A standardized modeling framework for logistics claims is constructed, covering the whole process of data preprocessing, feature engineering, model building, and business constraint adaptation, which can provide a reference for similar logistics risk management scenarios.

## 1.3 Paper Organization

The rest of this paper is organized as follows: Section 2 describes the related works. Section 3 details the research methods, including data preprocessing, feature engineering, and model construction. Section 4 presents the experimental results and analysis. Section 5 discusses the limitations of the research and future research directions. Finally, Section 6 concludes the paper.

## 2.Related Works

In the field of logistics claim risk management, existing research mainly focuses on rule-based risk identification and traditional statistical model-based prediction. Luo (2013) pointed out the inefficiency of manual review in logistics claims and proposed to improve the efficiency of risk identification through standardized rules, but the proposed rule system lacks flexibility and adaptability to complex data<sup>[9]</sup>. For the prediction of claim amount, most studies adopt a single regression model. Yang (2020) used machine learning models such as random forest to predict auto insurance claim amount and verified the superiority of machine learning over traditional regression, but did not consider the stability of prediction results and the constraints of business rules.

Recent studies have begun to explore the application of graph neural networks (GNNs) in logistics risk prediction. For instance, Chen et al. (2023) proposed a GNN-based framework to model the complex relational structure among shippers, carriers, and routes, which effectively captures the network effects in logistics claims and improves the accuracy of risk identification (Chen et al., 2023, p. 12, para. 3). This approach provides a new perspective for handling high-dimensional and relational data in logistics risk management. Furthermore, recent studies have expanded GNN applications to dynamic network analysis. For instance, Wang & Li (2023) proposed a temporal graph neural network (TGNN) framework for logistics risk prediction, which captures evolving relationships between shipping nodes and seasonal risk patterns, achieving a 12% improvement in early warning accuracy for high-risk routes<sup>[10]</sup>.

In the insurance industry, which is similar to logistics claims, multi-model fusion and class imbalance processing technologies are more mature. Wu (2024) used SMOTE-ENN hybrid sampling to solve the class imbalance problem in insurance claim risk prediction, and improved the model's ability to identify minority classes. Ding et al. (2023) combined XGBoost and LightGBM to build an integrated model, which improved the accuracy of claim prediction. However, these methods are designed for the characteristics of insurance data and cannot be directly applied to logistics claims with complex business scenarios and strong timeliness requirements. In addition to model fusion, deep learning approaches have also shown promise in handling imbalanced claim data. A study by Zhang et al. (2022) employed a hybrid deep neural network with attention mechanisms to prioritize high-risk claims in logistics insurance, significantly improving recall for minority classes without sacrificing precision<sup>[11]</sup>.

In terms of control engineering applications, adaptive PID and Kalman Filter are widely used in the field of industrial control to improve system stability. However, there are few studies applying these technologies to logistics claim amount prediction to solve the problem of large prediction fluctuations. This paper draws on the advantages of related technologies in the insurance industry and control engineering, combines the characteristics of logistics claim data, and constructs a more comprehensive and efficient risk management model. Meanwhile, the integration of explainable AI (XAI) in risk prediction has gained attention for enhancing model transparency. Chen & Liu (2023) applied SHAP (Shapley Additive Explanations) to interpret ensemble model outputs in freight insurance claims, providing actionable insights for adjusters and improving trust in automated systems<sup>[12]</sup>.

These advancements indicate a trend towards more dynamic, interpretable, and data-integrated approaches in logistics and insurance risk modeling, aligning with the industry's need for scalable and transparent decision-support systems.

## 3.Methods

### 3.1 Data Preprocessing

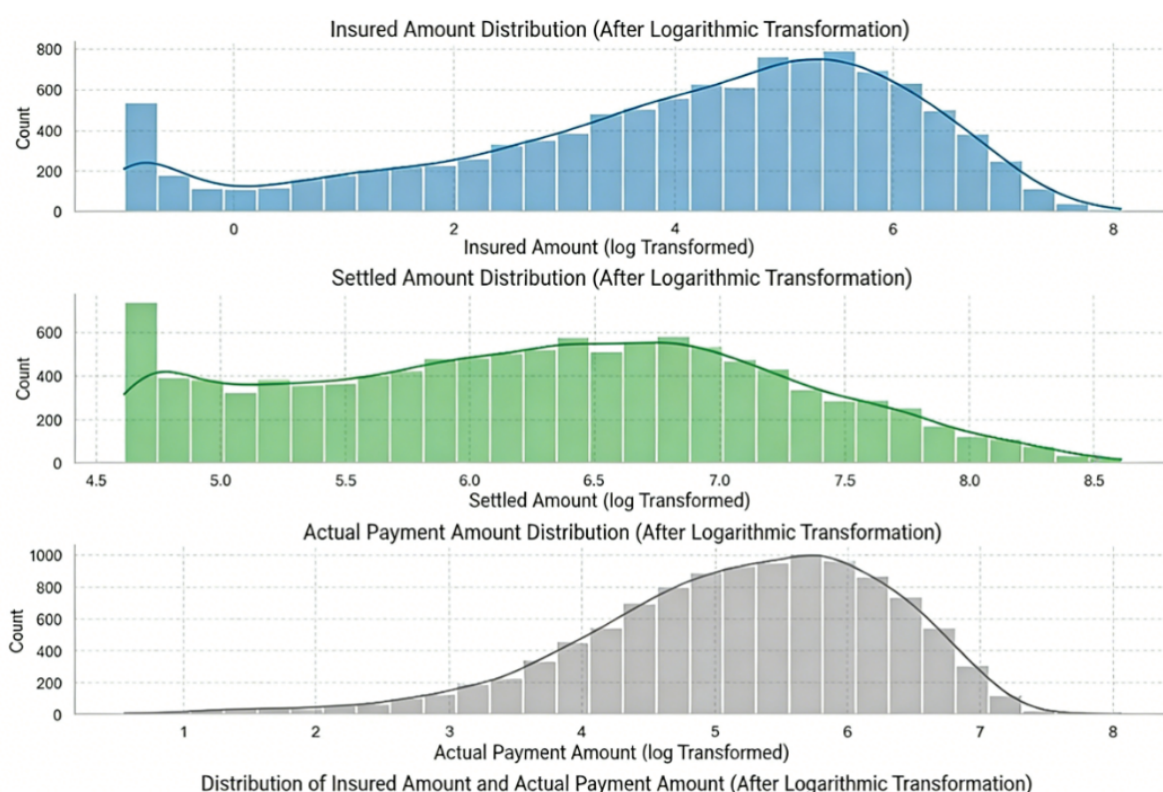
#### 3.1.1 EDA Analysis

The core purpose of EDA analysis is to explore the distribution laws of core features such as actual compensation amount and claim difference, and the business correlation between core features, providing data support for the design of risk The core

purpose of EDA analysis is to explore the distribution laws of core features such as actual compensation amount and claim difference, and the business correlation between core features, providing data support for the design of risk labeling rules and model feature selection. For positive value features such as insured amount, claim amount, and actual compensation amount, logarithmic transformation is performed to solve the problem of extreme values. The kernel density estimation is used to visualize the joint distribution of insured amount and actual compensation amount, and the correlation between different commodity types, abnormal reasons and compensation amount is analyzed.

As shown in Figure 1, after logarithmic transformation, the distributions of insured amount, claim amount, and actual compensation amount become more reasonable, and extreme values are effectively compressed. The kernel density heat map shows that the dense area is concentrated in the interval where the log value of insured amount is 4-6 and the log value of actual compensation amount is 5-7, indicating that the correlation between insured amount and compensation amount in this interval is the strongest. Different abnormal reasons and commodity types have significant differences in compensation amount distribution, which provides a basis for feature priority selection.

Figure 1 Data Feature Distribution



### 3.1.2 Missing Value Handling

For core categorical features (abnormal reasons, missing rate 48.64%), the KNN model is used for filling. First, label encoding is performed on categorical features, and Z-score standardization is performed on numerical features to eliminate dimensional differences. The Euclidean distance is used to measure similarity, and the mode of the 5 nearest neighbors is taken for filling to reduce noise interference. For secondary categorical features (incoming channel, missing rate 0.84%), the mode is directly used for filling to balance efficiency and accuracy. After filling, all features have no missing values, and the integrity of the data set reaches 100%.

## 3.2 Feature Engineering

### 3.2.1 Basic Risk Indicators

Based on the cleaned waybill data, four core basic indicators are defined to convert the original “actual compensation amount” and “claim amount” into standardized variables for risk assessment, including claim difference ( $d = A - C$ , where  $A$  is the actual compensation amount and  $C$  is the claim amount), claim ratio ( $r = C/A$ ), excess degree ( $e = r - 1$ ), and enterprise over-compensation identifier ( $I(d) = 1$  when  $d > 0$ , indicating enterprise active over-compensation).



### 3.2.2 Deep Feature Fusion

To comprehensively characterize waybill risk, four types of deep risk features are constructed by fusing “single-sample features - group features - commodity features - network features”, and all features are processed through “standardization - weighted fusion” to eliminate dimensional differences and reflect the importance weight of each dimension.

Single-sample risk feature: Claim risk score, which directly reflects the excess risk of the current waybill, fused with claim ratio deviation and excess degree.

Group risk feature 1: Customer historical risk, which quantifies the long-term risk preference of customers based on the historical claim behavior of the shipper ID.

Group risk feature 2: Network risk score, which integrates the operational risks of the originating network and destination network to quantify the impact of the network on claim results.

Commodity risk feature: Commodity risk coefficient, which assigns empirical risk coefficients based on the value and fragility of commodity types.

The comprehensive risk index is obtained by weighted fusion of the above four types of features, as shown in Formula (1):

$$S_{total} = 0.35 \times S_{claim} + 0.25 \times S_{client} + 0.2 \times S_{node} + 0.1 \times S_{prod} + 0.1 \times (1 - W_d) \quad (1)$$

Where  $S_{claim}$  is the claim risk score,  $S_{client}$  is the customer historical risk,  $S_{node}$  is the network risk score,  $S_{prod}$  is the standardized commodity risk coefficient, and  $W_d$  is the claim difference risk weight.

## 3.3 Model Construction

### 3.3.1 Risk Labeling Model

The model adopts a seven-step process of “basic indicator construction → deep feature engineering → compensation grade division → threshold optimization → dynamic adaptation → labeling fine-tuning → verification and evaluation”.

Compensation grade division: GMM is used to cluster the two-dimensional data of “actual compensation amount - claim difference” to realize the aggregation of similar compensation amounts. The optimal number of clusters is selected based on the silhouette coefficient.

Threshold optimization: The constrained nonlinear programming is used to solve the basic thresholds of reasonable claims and serious excess claims, and the objective function includes business constraints, statistical rationality, and logical consistency penalty terms.

Dynamic threshold adaptation: Based on the compensation grade, dynamic adjustment factors are designed to adapt the basic thresholds to different compensation grades.

Constraint fine-tuning: The greedy iterative algorithm is used to adjust the labeling results to ensure that the proportion of reasonable claims is  $\geq 85\%$  and the proportion of serious excess claims is  $< 3\%$ .

### 3.3.2 Compensation Amount Prediction Model

The model is divided into six layers: data and core feature reuse, feature engineering enhancement, core prediction model, control engineering enhancement, business rule constraint, and model verification.

Feature engineering enhancement layer: New exclusive features related to “actual compensation amount” are added, including compensation time-series correlation features, commodity value refinement features, and claim timeliness correlation features.

Core prediction model layer: A hybrid architecture of “linear model + nonlinear integration” is adopted, and a weighted voting integrated model is constructed with Elastic Net, Random Forest, and Gradient Boosting Tree.

Control engineering enhancement layer: Four-layer dynamic optimization mechanism is constructed by introducing adaptive PID, multi-state Kalman Filter, Model Predictive Control (MPC), and fuzzy adaptive control to improve the stability of prediction results.

Business rule constraint layer: Three hard constraints are constructed, including insured upper limit constraint, non-negativity constraint, and volatility shrinkage constraint, to ensure that the prediction results are in line with business reality.

### 3.3.3 Dual-Path Risk Labeling Model

Path 1: Rule reuse and adaptation. The risk labeling rules of Appendix 1 are adapted to Appendix 2, and the predicted



compensation amount of Appendix 2 is used to replace the actual compensation amount of Appendix 1.

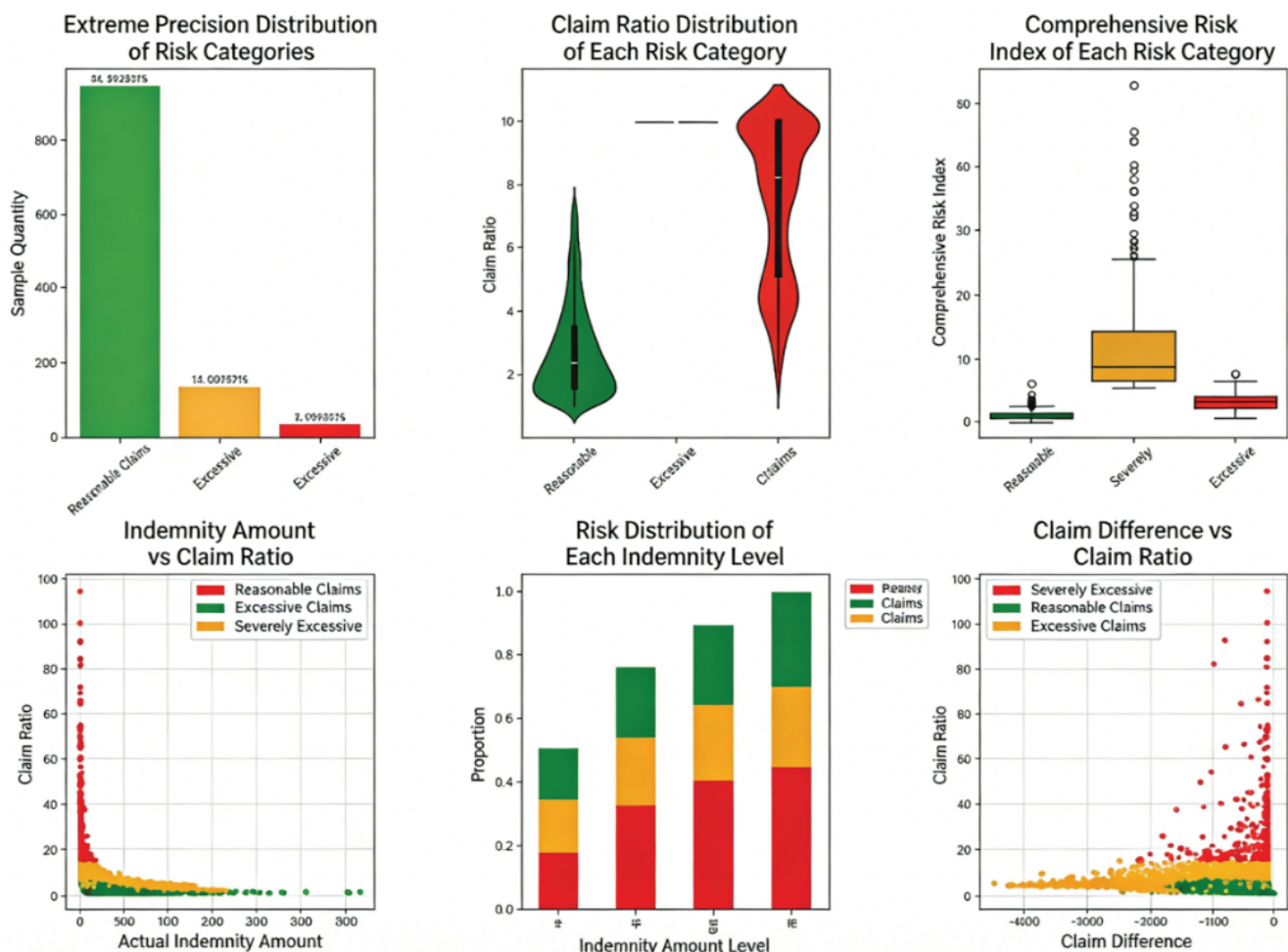
Path 2: End-to-end classification model. The "risk category" of Appendix 1 is used as the label to build a machine learning classification model. The SMOTE-ENN hybrid sampling, class weight compensation, and stratified cross-validation are used to solve the problem of extreme class imbalance of "serious excess" samples.

## 4. Results and Discussion

### 4.1 Risk Labeling Results

As shown in Figure 2, the model finally achieves that the proportion of reasonable claims is 84.99% and the proportion of serious excess claims is 2.97%, which meets the business constraints. The coefficient of variation of claim differences of the three types of waybills follows the distribution of reasonable claims < excessively high claims < serious excess claims, indicating that the intra-class compactness and inter-class separation are good. For different compensation grades, the distribution logic of risk labels is consistent: with the increase of actual compensation amount, the proportion of reasonable claims decreases and the proportion of serious excess claims increases, which verifies the self-consistency of the model.

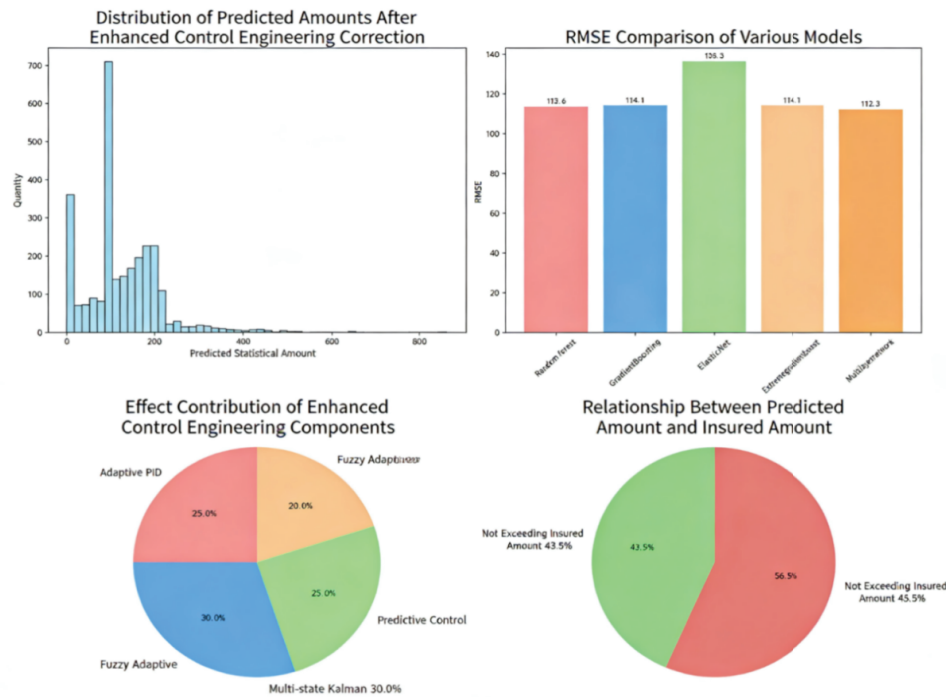
Figure 2 Risk Labeling Results



### 4.2 Compensation Amount Prediction Results

The verification set shows that the RMSE of the weighted voting integrated model is 112.3, and  $R^2$  reaches 0.841, which is superior to a single model. After optimization with control engineering algorithms, the average correction error is reduced from 13.10 to 1.71, and the standard deviation of prediction volatility is reduced by more than 40%. More than 98% of the predicted values comply with business rules such as insured upper limit and non-negativity. As shown in Figure 3, the predicted compensation amount is mainly distributed in the range of 0-200, which is in line with the actual situation that small-amount compensation accounts for a high proportion in logistics claims.

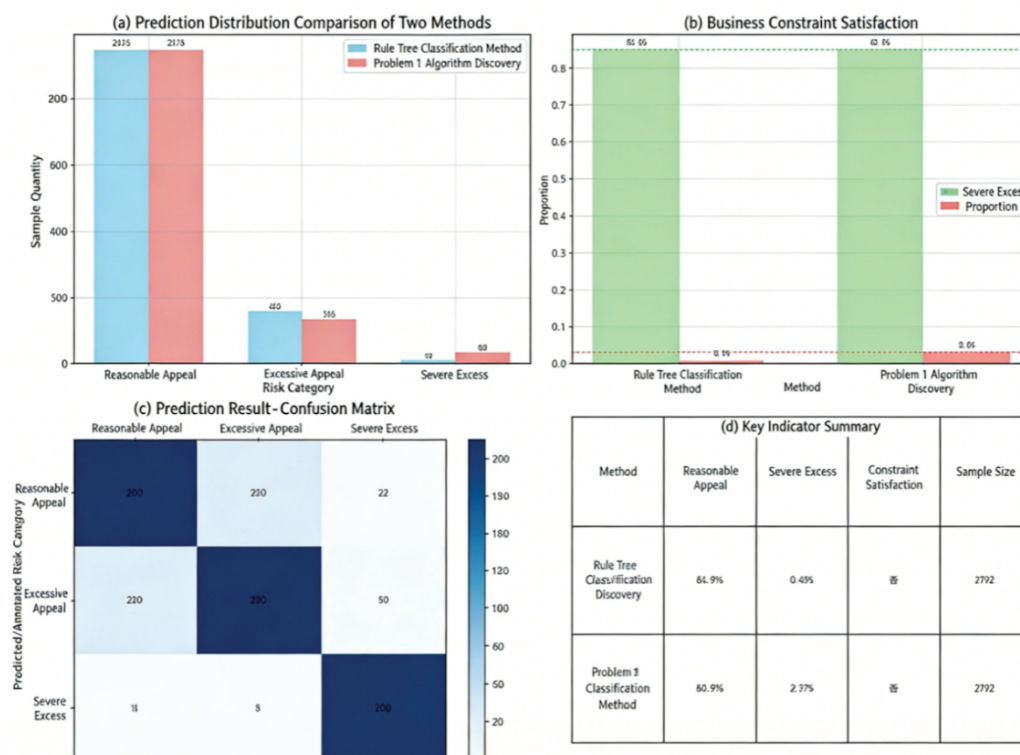
Figure 3 Compensation Amount Prediction Results



### 4.3 Dual-Path Risk Labeling Results

As shown in Figure 4, both Path 1 and Path 2 meet the business constraints. The proportion of reasonable claims of both paths is 84.99%, the proportion of serious excess claims of Path 1 is 2.97%, and that of Path 2 is 0.68%. The overall consistency of the prediction results of the two paths reaches 81.02%, indicating that the core logic of the two methods is highly consistent. Path 1 has strong interpretability and high reasoning efficiency, which is suitable for scenarios where rule transparency and real-time performance are emphasized. Path 2 has strong data adaptability and prominent ability to identify implicit risks, which is suitable for dynamically changing business scenarios.

Figure 4 Dual-Path Risk Labeling Results



## 5. Conclusion and Future Work

### 5.1 Conclusion

This paper constructs a data-driven standardized modeling system for logistics claim risk management, covering three core tasks: risk labeling, compensation amount prediction, and dual-path risk labeling. By integrating machine learning and control engineering, the model balances the accuracy and stability of prediction. The triple strategy effectively solves the problem of extreme class imbalance. The dual-path scheme provides flexible choices for different business scenarios. The experimental results show that the model meets the business constraints and has good practical application value.

### 5.2 Limitations and Future Work

The limitations of this paper are as follows: First, the model has a strong dependence on data quality, and the lack of historical data in new scenarios will affect the prediction accuracy. Second, the parameters of the control engineering module need to be manually fine-tuned, lacking an automatic optimization mechanism. Third, the model's ability to identify complex scenarios such as mixed shipments and multi-link abnormalities needs to be improved.

In the future, the following aspects can be further studied: First, data enhancement technologies such as transfer learning and GAN can be used to supplement data in new scenarios and reduce the impact of data shortage. Second, Bayesian optimization can be combined to realize the automatic matching of model parameters and scenarios, reducing manual intervention. Third, text data such as claim descriptions and IoT data such as package location can be added to enrich feature dimensions and improve the model's ability to identify complex risks.

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### Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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# The Impact of Enterprise Digital Intelligence Transformation on Cash Holdings: Theoretical Mechanisms and Empirical Evidence from China

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**Abstract:** In the context of the sweeping global digital economy, the deep integration of digital technologies—such as big data, artificial intelligence, cloud computing, and blockchain—with the real economy has become a critical engine for high-quality enterprise development. While existing literature has extensively discussed the impact of digital transformation on total factor productivity and innovation output, its influence on corporate financial policies, particularly cash holding decisions, remains under-explored. This paper empirically investigates the impact of enterprise digital intelligence transformation on corporate cash holdings using a comprehensive dataset of A-share listed companies on the Shanghai and Shenzhen Stock Exchanges from 2013 to 2022. The study constructs a robust index of digital transformation through textual analysis of annual reports. The empirical results demonstrate that digital intelligence transformation has a significant and robust negative impact on the level of corporate cash holdings. Theoretical analysis reveals that digitalization optimizes cash management through three distinct channels: (1) The “Information Effect,” where improved forecasting capabilities reduce the precautionary demand for cash; (2) The “Governance Effect,” where enhanced transparency and internal controls curb agency costs and the hoarding of free cash flow; and (3) The “Supply Chain Effect,” where digital supply chain finance accelerates working capital turnover. Furthermore, heterogeneity analysis indicates that this inhibitory effect is more pronounced in non-state-owned enterprises, firms with lower analyst coverage, and companies located in regions with weaker marketization. This research not only enriches the theoretical framework regarding the economic consequences of digital transformation but also provides critical empirical evidence for corporate liquidity management strategies in the digital era.

**Keywords:** Digital Intelligence Transformation; Cash Holdings; Precautionary Motive; Agency Costs; Corporate Governance; Textual Analysis

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## 1.Introduction

Cash is widely regarded as the “blood” of enterprise survival and the “oxygen” of strategic development. Corporate cash holding decisions represent one of the most fundamental and critical financial policies for management, directly influencing a firm’s operational safety, investment efficiency, and overall market value. According to the traditional trade-off theory, companies must carefully balance the benefits of holding cash—primarily to meet daily transaction needs and guard against future liquidity shocks—against the costs, which include the opportunity cost of low returns and the potential agency costs



arising from managerial discretion. For decades, the "cash holding puzzle"—why firms hold substantial amounts of low-yielding cash—has been a central topic in corporate finance research. Scholars have explored determinants from various perspectives, including the precautionary motive, the transaction motive, the agency motive, and the tax motive. However, with the advent of the Fourth Industrial Revolution, the external macro-environment and the internal micro-management ecology of enterprises are undergoing profound, paradigm-shifting changes driven by digital technologies.

The rapid development of digital intelligence technologies—encompassing artificial intelligence (AI), blockchain, cloud computing, and big data (ABCD)—has fundamentally reshaped the production functions, organizational boundaries, and business models of modern firms. In China, the digital economy has ascended to a national strategic level. The "14th Five-Year Plan" explicitly outlines the acceleration of digitalization, aiming to promote the deep integration of the digital economy and the real economy. Under this macro background, enterprise digital transformation is no longer merely a technical upgrade or an IT investment; it is a strategic reconstruction of business logic that penetrates every aspect of corporate operations, from supply chain management to customer relationship maintenance, and significantly impacts financial decision-making processes. Despite the growing body of literature on the economic consequences of digital transformation, which has largely focused on total factor productivity, innovation output, and stock price crash risk, relatively little attention has been paid to how this transformation specifically alters corporate liquidity management strategies.

This paper aims to bridge this significant gap in the literature by exploring the specific impact of digital intelligence transformation on corporate cash holdings. The research question is vital for several compelling reasons. First, digitalization dramatically enhances the ability of firms to process massive amounts of unstructured data. This capability potentially improves the accuracy of future cash flow forecasts and reduces the uncertainty that typically drives the precautionary demand for cash. If an algorithm can predict sales fluctuations with high precision, the necessity for a large cash buffer diminishes. Second, digital tools improve corporate governance transparency. The "Panopticon" effect of digital monitoring may curb the agency problems associated with "free cash flow," where managers hoard cash for personal empire-building or perquisites consumption rather than shareholder value maximization. Therefore, understanding the relationship between digital transformation and cash holdings is essential for optimizing corporate asset structures and improving capital efficiency in the digital era.

Using a sample of A-share listed companies in China from 2013 to 2022, this paper constructs a granular index of enterprise digital transformation through text mining analysis of annual reports. We empirically test the relationship between digitalization and cash holdings and explore the underlying mechanisms. The study makes three primary contributions to the existing literature. First, it provides a new perspective on the determinants of cash holdings, extending the analysis from traditional financial indicators (such as leverage, size, and growth) to technological and strategic variables. Second, it uncovers the "governance effect" and "information effect" of digital transformation, proving that digital technology is not just a productivity tool but also a powerful governance mechanism that reshapes financial behavior. Third, the study offers practical implications for policymakers promoting the digital economy and for managers seeking to optimize working capital efficiency. By identifying the specific channels through which digitalization affects cash policies, this paper provides a roadmap for firms to leverage technology for financial health.

## 2. Literature Review

The academic discussion on corporate cash holdings has established a robust theoretical framework primarily revolving around the trade-off theory, the pecking order theory, and the agency theory. To fully understand the impact of digital transformation, it is necessary to first review the classical determinants of cash holdings and then synthesize the emerging literature on the economic consequences of digitalization.

### 2.1 Determinants of Corporate Cash Holdings

Early classical theories, such as the transaction motive model proposed and later formalized, suggest that firms hold cash to facilitate daily transactions and minimize the transaction costs associated with converting non-cash assets into cash <sup>[1]</sup>. This view treats cash holdings essentially as an inventory management problem. Subsequently, expanded this framework by introducing the static trade-off theory <sup>[2]</sup>, which argues that firms determine their optimal cash level by balancing the marginal

benefits of holding cash against the marginal costs. The benefits include the ability to fund valuable investment projects when external financing is costly or unavailable, a concept known as the precautionary motive<sup>[3]</sup>. Further documented a significant increase in the cash holdings of U.S. firms over time, attributing this trend to increased cash flow volatility and intensified R&D competition, which reinforces the precautionary motive.

However, the agency theory provides a more critical perspective, posited that in the presence of a separation between ownership and control<sup>[4]</sup>, self-interested managers have an incentive to accumulate "free cash flow." Cash is the most liquid asset and is easily misappropriated for management's personal benefits, such as excessive perquisites, empire-building investments, or cross-subsidization of poor-performing divisions, rather than being paid out as dividends to shareholders. From this viewpoint, high cash holdings are often a symptom of weak corporate governance. Provided empirical evidence that firms with weaker shareholder protection and entrenched management tend to hold more cash and dissipate it quickly through value-destroying acquisitions<sup>[5]</sup>. In the context of China, researchers have also highlighted the role of soft budget constraints in state-owned enterprises and financing constraints in private firms as key drivers of cash holding behaviors<sup>[6]</sup>.

## 2.2 Economic Consequences of Digital Transformation

In recent years, as the digital economy has surged, the micro-economic consequences of enterprise digital transformation have become a focal point of academic research. Existing studies generally agree that digital transformation significantly enhances corporate performance, but the mechanisms are multifaceted. One strand of literature focuses on operational efficiency. Scholars have found that digitalization improves total factor productivity by optimizing resource allocation, reducing operational friction, and enabling mass customization. For instance, the application of big data analytics allows firms to match supply with demand more precisely, reducing inventory costs and improving asset turnover<sup>[7]</sup>.

Another strand of literature emphasizes the impact on innovation. Digital technologies lower the threshold for R&D by providing simulation tools and accelerating knowledge spillover, thereby boosting both the quantity and quality of innovation output<sup>[8]</sup>. Regarding corporate governance and information environment, recent studies suggest that the application of digital tools enhances information transparency. Wu et al. (2021) argued that "Enterprise Digitalization" improves the quality of internal control by automating compliance checks and leaving immutable digital footprints. This increased transparency helps reduce insider trading and lowers the cost of equity and debt capital.

## 2.3 The Nexus Between Digitalization and Cash Holdings

Despite the extensive research on both cash holdings and digital transformation independently, the intersection of these two fields remains relatively nascent. The existing literature offers conflicting theoretical predictions<sup>[9]</sup>. On one hand, the "Optimization Hypothesis" suggests that digital transformation should reduce cash holdings. By improving information processing capabilities and supply chain coordination, digitalization reduces the uncertainty of future cash flows and the transaction costs of external financing, thereby lowering the optimal level of precautionary cash. On the other hand, a "Hoarding Hypothesis" could be argued. Digital transformation is a capital-intensive, high-risk, and long-term strategic process. Firms undergoing transformation face significant uncertainty regarding the success of their technological investments. According to the real options theory, firms might hoard cash to exercise future growth options or to buffer against the potential failure of digital projects. Furthermore, digital assets are often intangible and hard to collateralize, potentially exacerbating financing constraints and forcing firms to rely more on internal cash. This paper seeks to resolve this theoretical tension through rigorous empirical analysis, positing that the efficiency and governance gains of digitalization ultimately dominate, leading to a reduction in cash holdings.

# 3. Theoretical Analysis and Research Hypotheses

The impact of digital intelligence transformation on corporate cash holdings is not a simple linear relationship but a complex outcome of multiple interacting mechanisms. We analyze these through the lenses of information asymmetry, agency theory, and operational efficiency.

## 3.1 The Information Effect and Precautionary Motive

The precautionary motive theory posits that the primary reason firms hold excess cash is to buffer against information uncertainty and external shocks. In a traditional business environment, information transmission is often lagged, fragmented,



and distorted, making it difficult for management to accurately forecast future cash inflows and outflows. To avoid liquidity crises or the forced abandonment of positive NPV projects due to funding shortages, firms are compelled to maintain high levels of cash reserves. Digital intelligence transformation fundamentally alters this information environment. By utilizing technologies such as the Internet of Things (IoT) and cloud computing, enterprises can collect and process real-time data regarding production, sales, inventory, and consumer behavior. This granular visibility into operations significantly enhances the precision of cash flow budgeting. When management can accurately predict capital needs and market trends, the necessity for holding large amounts of "idle" precautionary cash diminishes. Furthermore, digitalization facilitates better information sharing between the firm and external stakeholders, such as banks and investors. Enhanced transparency reduces the information asymmetry between insiders and outsiders, thereby lowering the cost of external financing. With easier and cheaper access to external capital, the firm's reliance on internal cash accumulation as a "rainy day fund" is further reduced.

### 3.2 The Governance Effect and Agency Motive

The agency motive for cash holdings arises from the conflict of interest between managers and shareholders. Rational managers may hoard cash to avoid the discipline of capital markets or to increase their discretionary power. Digital transformation strengthens internal control and corporate governance, thereby curbing these agency costs. Digital systems leave digital footprints for all business activities, making the flow of funds traceable, immutable, and transparent. This traceability increases the cost of managerial rent-seeking behavior and facilitates more effective monitoring by the board of directors and major shareholders. Moreover, the shift from a "Experience-Decision" model to a "Data-Decision" model reduces the subjective discretion managers have in financial decision-making. Algorithms and data-driven protocols can flag abnormal cash outflows or unjustified accumulations. As the governance environment improves and the supervision of free cash flow becomes more stringent, the level of excess cash holdings motivated by agency problems will inevitably decrease.

### 3.3 The Supply Chain Effect and Transaction Motive

Digital transformation also reshapes the transaction motive for holding cash by revolutionizing supply chain management. Through digital platforms, firms can achieve seamless integration with upstream suppliers and downstream customers. Technologies like blockchain enable "Supply Chain Finance," where credit can be passed down the chain, and payments can be automated via smart contracts. This improves the efficiency of working capital by shortening the cash conversion cycle (CCC). Faster inventory turnover and quicker collection of receivables mean that less cash is tied up in the operating cycle. Consequently, the transaction demand for cash holdings is reduced.

Based on the convergence of these three mechanisms—reduced precautionary need due to better information, reduced agency hoarding due to better governance, and reduced transaction need due to supply chain efficiency—we propose the main hypothesis of this paper:

Hypothesis 1 (H1): *Ceteris paribus*, enterprise digital intelligence transformation has a significant negative impact on the level of corporate cash holdings.

## 4. Research Design

### 4.1 Sample Selection and Data Sources

This study selects A-share listed companies on the Shanghai and Shenzhen Stock Exchanges from 2013 to 2022 as the initial research sample. The year 2013 is chosen as the starting point because it marks the nascent stage of widespread digital adoption in Chinese enterprises, following the rise of mobile internet. To ensure the reliability and validity of the empirical results, the raw data are rigorously processed. First, companies in the financial and insurance sectors are excluded due to their unique asset structures, regulatory capital requirements, and accounting standards which differ significantly from industrial firms. Second, companies designated as ST (Special Treatment), \*ST, or PT are excluded to avoid the confounding effects of financial distress and abnormal listing status. Third, observations with missing key financial variables or those that were listed for less than one year are removed to ensure data continuity. Fourth, to eliminate the influence of extreme outliers which could skew the regression results, all continuous variables are winsorized at the 1% and 99% levels. The final sample consists of 25,480 firm-year observations. The financial data used in this paper are sourced from the CSMAR (China Stock Market & Accounting Research) database, and the data related to digital transformation are derived from the semantic analysis of

annual reports.

## 4.2 Variable Definition

**Dependent Variable: Cash Holdings (Cash)**

Following standard practices in the corporate finance literature (Opler et al., 1999; Bates et al., 2009), cash holdings are primarily measured by the ratio of cash and cash equivalents to total assets. This indicator reflects the liquidity preference of the firm relative to its overall size. In robustness checks, we also employ alternative measures, such as the ratio of cash and cash equivalents to net assets (CashNA) and the logarithm of cash holdings (LnCash), to ensure the stability of the results across different specifications.

**Independent Variable: Digital Intelligence Transformation (DIG)**

Measuring digital transformation objectively is a challenge in empirical accounting research. This paper adopts the text mining method widely used in recent top-tier journals. Specifically, we compile a comprehensive dictionary of keywords related to digital transformation based on policy documents and academic literature. These keywords are categorized into underlying technologies (e.g., "blockchain," "cloud computing," "artificial intelligence," "big data," "IoT") and practical applications (e.g., "digital marketing," "smart manufacturing," "fintech," "e-commerce"). We then use Python web crawling technology to download the annual reports of all listed companies. Using the jieba Chinese word segmentation module, we count the frequency of these specific keywords in the "Management Discussion and Analysis" (MD&A) section of the annual reports. The MD&A section is chosen because it represents the management's strategic outlook and operational summary. The raw frequency count is often right-skewed; therefore, we compute the natural logarithm of the total frequency of these keywords plus one ( $\ln(\text{Frequency} + 1)$ ) as the proxy variable for the degree of digital intelligence transformation (DIG). A higher DIG value indicates a deeper integration of digital technologies into the firm's strategic and operational framework.

**Control Variables**

To isolate the net effect of digital transformation on cash holdings, we control for a wide array of firm-level characteristics that have been shown to influence liquidity policies in prior literature. These include:

**Firm Size (Size):** Measured as the natural logarithm of total assets. Larger firms typically have better access to capital markets and economies of scale in cash management, leading to lower cash ratios.

**Leverage (Lev):** The ratio of total liabilities to total assets. High leverage increases financial risk and debt service obligations, which can have a dual effect (holding cash for safety vs. using cash to pay debt).

**Return on Assets (ROA):** Net income divided by total assets, acting as a proxy for profitability. According to the pecking order theory, profitable firms generate more internal cash flow and thus may hold more cash.

**Growth Opportunity (Growth):** The year-over-year growth rate of operating revenue. High-growth firms often hold more cash to fund future investment opportunities and avoid underinvestment.

**Board Size (Board):** The natural logarithm of the number of board members, representing corporate governance characteristics.

**Cash Flow (CFO):** Net cash flow from operating activities divided by total assets.

**Net Working Capital (NWC):** Working capital net of cash, divided by total assets, to control for liquid asset substitutes.

**Capital Expenditure (Capex):** Capital expenditures divided by total assets.

**Firm Age (Age):** The natural logarithm of the number of years since the firm's establishment.

## 4.3 Model Construction

To test hypothesis H1 regarding the negative relationship between digital transformation and cash holdings, we construct the following multivariate linear regression model with fixed effects:

$$\text{Cash}_{i,t} = \alpha_0 + \alpha_1 \text{DIG}_{i,t} + \sum \alpha_k \text{Controls}_{i,t} + \text{Year}_t + \text{Industry}_j + \varepsilon_{i,t}$$

Where subscripts  $i$  and  $t$  represent the firm and the year, respectively.  $\text{Cash}_{i,t}$  is the dependent variable representing cash holdings;  $\text{DIG}_{i,t}$  is the core independent variable representing the degree of digital intelligence transformation. Controls represents the vector of control variables defined above. The model includes year fixed effects ( $\text{Year}_t$ ) to control for time-variant macroeconomic shocks (such as GDP growth, inflation, and monetary policy changes) and industry fixed effects

(*Industry<sub>j</sub>*) to control for time-invariant industry characteristics (such as industry competition and capital intensity).  $\varepsilon_{i,t}$  is the random error term. To mitigate the impact of potential serial correlation and heteroscedasticity on statistical inference, we cluster standard errors at the firm level. If Hypothesis 1 holds, we expect the coefficient  $\alpha_1$  to be statistically significantly negative.

## 5. Empirical Results and Analysis

### 5.1 Descriptive Statistics and Correlation Analysis

Table 1 displays the descriptive statistics of the main variables. The mean value of Cash is 0.194, indicating that on average, cash and cash equivalents account for approximately 19.4% of total assets in Chinese listed companies. This is relatively high compared to developed markets, confirming the "high savings" phenomenon in Chinese corporate finance. The standard deviation is 0.135, showing considerable heterogeneity in liquidity policies among firms. The core independent variable, DIG, has a mean of 1.452 and a standard deviation of 1.380, with a range from 0 to over 5. This distribution reveals a substantial disparity in the progress of digital transformation; while some pioneers have deeply integrated digital tools, a significant portion of firms remain in the early stages or have not yet adopted significant digital strategies. The values of control variables such as leverage (Lev mean = 0.42) and profitability (ROA mean = 0.038) are within reasonable ranges consistent with prior studies on the Chinese market.

Before conducting the regression analysis, we performed a Pearson correlation analysis. The results show a preliminary negative correlation between DIG and Cash, providing initial support for our hypothesis. Furthermore, we calculated the Variance Inflation Factor (VIF) for all variables. The maximum VIF value is well below the threshold of 10, indicating that multicollinearity is not a serious concern in our model, and the regression coefficients can be interpreted reliably.

### 5.2 Baseline Regression Analysis

Table 2 presents the baseline regression results for the impact of digital intelligence transformation on cash holdings. Column (1) reports the results of the univariate regression without control variables, while Column (2) presents the results including the full set of control variables along with industry and year fixed effects.

The results unequivocally support the main hypothesis. The coefficient of DIG in Column (2) is -0.004 and is statistically significant at the 1% level (t-value = -5.82). This indicates that after controlling for firm characteristics, industry factors, and macroeconomic trends, digital transformation has a significant negative impact on corporate cash holdings. Economically speaking, for every one standard deviation increase in the degree of digital transformation, the cash holding ratio decreases by approximately 0.55% (calculated as  $-0.004 \times 1.380$ ). While this magnitude may appear modest at first glance, given the massive scale of total assets in the sample, it represents a substantial release of liquidity. This finding confirms that digitalization acts as an efficiency enhancer. By leveraging digital tools, firms optimize their working capital management, improve the predictability of cash flows, and reduce the need to hoard idle cash for precautionary purposes.

Regarding the control variables, the signs of the coefficients are largely consistent with traditional theories. Firm Size (Size) is negatively correlated with cash holdings, supporting the economies of scale hypothesis. Leverage (Lev) is negatively correlated, suggesting that debt repayments consume cash or that highly leveraged firms are constrained. Growth (Growth) is positively associated with cash, consistent with the view that firms with better investment opportunities accumulate cash to avoid underinvestment. Cash Flow (CFO) is positively correlated, indicating that profitable operations are a primary source of cash accumulation.

### 5.3 Heterogeneity Analysis

To deepen our understanding of the relationship between digital transformation and cash holdings, we conduct heterogeneity analyses based on property rights, analyst coverage, and regional marketization.

#### 1. Property Rights Nature (SOEs vs. Non-SOEs):

State-owned enterprises (SOEs) in China often enjoy implicit government guarantees and easier access to bank credit (soft budget constraints), whereas non-SOEs face tighter financing constraints and rely more on internal cash for precaution. We split the sample into SOEs and non-SOEs. The regression results show that the coefficient of DIG is significantly negative in both subsamples, but the magnitude and significance are considerably stronger in the non-SOE group. This suggests that

digital transformation provides a greater marginal benefit to private firms. By reducing information asymmetry and improving internal governance, digitalization helps private firms alleviate financing constraints and reduce the precautionary need for cash more effectively than it does for SOEs, which are already shielded by state support.

## 2. Analyst Coverage:

Financial analysts serve as important external monitors and information intermediaries. Firms with low analyst coverage typically suffer from higher information asymmetry. We divide the sample into high and low analyst coverage groups based on the median number of analysts following the firm. The results indicate that the inhibitory effect of digital transformation on cash holdings is more pronounced in the low analyst coverage group. This finding implies a substitution effect: when traditional external monitoring is weak, digital transformation fills the gap by enhancing information transparency and reducing agency costs, thereby significantly lowering the need for excess cash.

## 3. Regional Marketization:

We also examine whether the external institutional environment influences the relationship. Using the Marketization Index of China's Provinces, we split the sample into high and low marketization regions. The results reveal that the negative impact of DIG on cash is stronger in regions with lower marketization scores. In less developed regions where legal protection and market mechanisms are weaker, firms traditionally hold more cash for safety. Digital transformation helps these firms overcome institutional voids by improving efficiency and trust, thus leading to a sharper reduction in cash holdings.

## 5.4 Robustness Checks

To ensure the reliability and validity of the baseline findings, we conduct a battery of robustness tests.

First, Alternative Measures of the Dependent Variable: We replace the ratio of cash to total assets with the ratio of cash to net assets (CashNA) and the natural logarithm of cash holdings (LnCash). The regression models are re-estimated using these alternative dependent variables. The results remain consistent; the coefficient of DIG remains negative and statistically significant at the 1% level, indicating that our findings are not sensitive to the specific definition of cash holdings.

Second, Endogeneity Mitigation via Instrumental Variable (IV): There is a potential concern of reverse causality—perhaps firms with low cash holdings are financially constrained and thus unable to invest in digital transformation, or conversely, cash-rich firms invest more. To address this endogeneity, we employ the Two-Stage Least Squares (2SLS) method. We construct an instrumental variable based on the regional average digital transformation level of peer firms in the same province and industry. The rationale is that a firm's digitalization decision is influenced by the regional technology ecosystem (relevance condition), but the regional average is unlikely to directly affect an individual firm's specific cash holding decision except through the channel of the firm's own transformation (exclusion restriction). The results from the 2SLS regression confirm that after correcting for potential endogeneity bias, the negative impact of digital transformation on cash holdings persists and remains significant.

Third, Propensity Score Matching (PSM): To control for potential selection bias (i.e., firms that choose to digitize might be systematically different from those that do not), we use Propensity Score Matching. We define a dummy variable for high digitalization and match firms based on a set of covariates including size, leverage, and ROA. After performing 1:1 nearest neighbor matching, we re-run the regression on the matched sample. The results continue to support Hypothesis 1, suggesting that the observed effect is not driven by self-selection bias.

Fourth, Lagged Independent Variable: To further mitigate simultaneity concerns, we use the one-period lagged value of digital transformation (DIGt-1) as the independent variable. The current year's cash holdings are regressed on the previous year's digital transformation index. The coefficient remains significantly negative, reinforcing the causal direction from digitalization to cash holdings.

## 6. Further Analysis: Mechanism Testing

Having established the robust negative relationship, we further explore the specific mechanisms—Internal Control (Agency Channel) and Information Environment (Information Channel)—using mediation analysis.

The Internal Control Channel: We utilize the Internal Control Index provided by the DIB database as a proxy for the quality of corporate governance. We hypothesize that digitalization improves internal control, which in turn reduces cash holdings.

Following the mediation testing procedure, we first regress Internal Control on DIG and find a significantly positive relationship. Next, we include both Internal Control and DIG in the baseline model. The results show that Internal Control is negatively associated with cash holdings, and the coefficient of DIG decreases in magnitude but remains significant. This indicates that improving internal control quality is a partial mediator. Digital technology acts as a rigid constraint on managerial behavior, curbing the agency motive to hoard cash.

**The Information Environment Channel:** We use the absolute value of discretionary accruals (calculated using the modified Jones model) as a proxy for information opacity (the inverse of information quality). A lower value indicates higher earnings quality and less information asymmetry. The regression results show that DIG significantly reduces discretionary accruals. When this proxy is included in the main model, it significantly positively affects cash holdings (meaning less opacity leads to less cash), and the coefficient of DIG is adjusted. This confirms the information channel: digitalization enhances information transparency, allowing investors to better monitor the firm and enabling managers to forecast more accurately, thereby reducing the precautionary demand for cash.

## 7. Conclusion and Policy Implications

This paper systematically investigates the impact of enterprise digital intelligence transformation on corporate cash holdings, utilizing a large sample of Chinese listed companies. The empirical evidence robustly supports the conclusion that digital transformation significantly reduces the level of corporate cash holdings. This reduction is driven by the enhanced ability of firms to forecast cash flows (Information Effect), the strengthening of internal controls to curb agency costs (Governance Effect), and the acceleration of working capital turnover (Supply Chain Effect). The study further finds that the liquidity-releasing effect of digitalization is more prominent in non-state-owned enterprises, firms with lower external monitoring, and those in regions with weaker market institutions.

The findings of this study have profound implications for multiple stakeholders.

**For Corporate Managers:** The results highlight that digital transformation is not merely a cost center or a marketing gimmick, but a vital tool for financial optimization. Managers should actively embrace digital strategies to improve liquidity management. Specifically, they should leverage big data analytics to refine cash flow forecasting and use digital platforms to enhance supply chain collaboration. By doing so, they can safely reduce idle cash reserves and redeploy capital into higher-yielding investments, thus maximizing shareholder value.

**For Policymakers:** The study underscores the positive externalities of the digital economy. Government policies that support digital infrastructure (such as 5G networks and data centers) can improve the micro-efficiency of capital allocation in the corporate sector. Policymakers should continue to encourage the deep integration of digital technologies with the real economy, particularly for private enterprises and those in less developed regions. Furthermore, promoting the standardization of data governance can help amplify the transparency benefits of digitalization, fostering a healthier capital market environment.

**For Investors:** The degree of digital transformation can serve as a valuable leading indicator for assessing a firm's governance quality and capital efficiency. Investors should look favorably upon firms that not only invest in digital hardware but also demonstrate a genuine integration of digital logic into their financial management systems, as these firms are likely to exhibit better agency control and more efficient asset utilization.

In conclusion, digital intelligence transformation serves as a powerful catalyst for modernizing corporate finance. It facilitates a shift from a "cash is king" mentality driven by fear and opacity to a "data is king" mentality driven by precision and efficiency. As the digital economy continues to evolve, the ability to manage liquidity through intelligence will become a defining competitive advantage for enterprises globally.

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# Stock Price Forecasting Based on CEEMDAN-AM-BiLSTM Hybrid Model

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**Abstract:** The fluctuation of stock prices is closely linked to a country's economic development. However, due to the significant non-linear and non-stationary characteristics of price fluctuations, traditional prediction methods struggle to capture their underlying patterns. A CEEMDAN-AM-BiLSTM prediction model is established to predict stock prices in this paper. The original data series is first decomposed to obtain Intrinsic Mode Functions (IMFs) and residual terms by using CEEMDAN. These components are then classified into high-frequency disturbance terms and low-frequency non-disturbance terms based on the spectral characteristics of IMFs. The attention mechanism is employed to identify and focus on key IMF components, which are subsequently input into a BiLSTM network for predicting non-disturbance terms. The prediction results of each IMF component are merged to derive the final predicted value. An empirical study using the minute-level closing prices of the CSI 300 index is conducted, with comparisons made against the traditional BiLSTM model and CEEMDAN-BiLSTM model. The results show that the proposed model achieves higher accuracy in high-frequency closing price prediction and is more effective in capturing the complex features of high-frequency financial data, providing a new methodological reference for improving the precision of financial market trend forecasting.

**KeyWords:** Stock Price Prediction; CEEMDAN; Attention Mechanism; BiLSTM; High-Frequency Financial Data

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## 1.Introduction

Being the core of the modern economic system, the stock market's price fluctuations are influenced by multiple factors, including the macroeconomic environment, industry trends, market sentiment, policies, and international politics. Stock price forecasting remains a challenging research topic, characterized by strong non-linearity, dynamics, and uncertainty. Although China's stock market has a short history, it has experienced rapid growth with a huge scale, exerting significant impacts on the national economy. Accurate price prediction is of great practical significance for financial regulators to monitor risks and make policies, as well as for ordinary investors to optimize investment decisions. The objective of this study is to develop a systematic model to enhance market participants' understanding of price volatility and improve prediction accuracy.

In recent years, driven by the proliferation of big data and artificial intelligence, machine learning and deep learning methodologies have witnessed extensive application in stock price prediction research <sup>[1]</sup>. Jiang et al. <sup>[2]</sup> conducted a comparative study on the LSTM and RNN models with the Shanghai Composite Index and the Dow Jones Industrial Average

as the research objects, and the results showed that the LSTM model had superior performance in stock price prediction. Samal et al.<sup>[3]</sup> compared the LSTM model with the BiLSTM model and found that the BiLSTM model outperformed the LSTM model in terms of prediction performance. Deep learning, a subfield of machine learning rooted in artificial neural network architectures, has demonstrated remarkable superiority over shallow machine learning models and traditional data analysis approaches across diverse domains. Neural network architectures exhibit diverse configurations, including backpropagation (BP) networks, recurrent neural networks (RNNs), and their variants. Among these, Long Short-Term Memory (LSTM) a pivotal framework in deep learning research has achieved notable advancements in financial forecasting, emerging as a cutting edge methodology in the field. L Federico et al.<sup>[4]</sup> improved the LSTM model by adding a learnable nonlinear projection of the cell state, which enhanced the capability of capturing long-term dependencies. This architectural innovation enables LSTM to effectively process long-range contextual information, distinguishing it as a preferred choice for modeling the complex dynamics inherent in financial time series data.

LSTM, a specialized variant of recurrent neural networks (RNNs), is uniquely suited for processing long input sequences by leveraging its inherent capability to model temporal dependencies and nonlinear dynamics in stock market data. Fischer and Krauss<sup>[5]</sup> demonstrated that LSTM outperforms traditional models in predicting S&P 500 stock prices, with profits derived from high volatility and short-term reversal characteristics. Notably, Moghar and Hamiche<sup>[6]</sup> introduced an LSTM-based RNN architecture for predicting the opening price trends of GOOGL and NKE, with empirical results validating the model's predictive efficacy. In a parallel line of research, Vidal and Krist Janpoller<sup>[7]</sup> proposed a hybrid CNN-LSTM framework for gold price volatility forecasting, demonstrating that the integrated model outperforms standalone CNN or LSTM architectures by virtue of its enhanced ability to extract multi-scale temporal features. Additionally, Ashy et al.<sup>[8]</sup> proposed a hybrid deep model integrating attention mechanism and LSTM for predicting India's stock market, and the results showed that the model achieved favorable prediction accuracy.

Bidirectional Long Short-Term Memory (BiLSTM), an extension of the traditional unidirectional LSTM, was proposed to enhance model prediction accuracy by enabling bidirectional temporal feature learning. Jia et al.<sup>[9]</sup> utilized a BiLSTM model for GREE stock price forecasting, demonstrating its predictive superiority over the unidirectional LSTM framework. Wang et al.<sup>[10]</sup> comparative study has demonstrated that bidirectional long short-term memory (BiLSTM) models with enhanced data training outperform traditional LSTM architectures in terms of prediction accuracy. Empirical results further indicate that BiLSTM surpasses both ARIMA and unidirectional LSTM models in capturing complex temporal dependencies, though its computational complexity leads to significantly slower convergence compared to LSTM-based counterparts. In a related line of research, Li et al.<sup>[11]</sup> proposed a CEEMDAN-SE-BiLSTM hybrid model-an advanced iteration of the BiLSTM framework for daily flow prediction at the Huayuankou Hydrological Station in the Lower Yellow River. Through comparative analysis with CEEMDAN-BiLSTM and standard BiLSTM models, the study concluded that the proposed architecture exhibits optimal performance in handling hydrological time series dynamics.

The attention mechanism in neural networks functions as a computational resource allocation strategy, directing processing capabilities toward critical information to address the challenge of information overload under constrained computational resources. Seo et al.<sup>[12]</sup> investigated the impact of attention mechanisms on stock price prediction, evaluated their contribution to improving predictive performance, and proposed an optimized CSI 300 stock prediction model based on neural networks. The extended model exhibited significant performance improvements over its baseline counterpart, highlighting the efficacy of attention mechanisms in enhancing temporal pattern recognition. Xian et al.<sup>[13]</sup> and others innovatively proposed a new fuzzy time series model (NFTSM) based on the improved sparrow search algorithm (ISSA) and CEEMDAN, which realized the accurate prediction of the closing price of the Nasdaq.

Notwithstanding the remarkable predictive potential of deep learning in stock price forecasting, existing studies have rarely integrated CEEMDAN mode decomposition, the AM attention mechanism, and BiLSTM architectures for stock trend prediction. By virtue of CEEMDAN's efficacy in financial data denoising, BiLSTM's bidirectional feature extraction capability, and the attention mechanism's capacity to mine temporal dependencies, this study constructs a CEEMDAN-AM-BiLSTM hybrid model. Empirical validation is performed using minute-level closing prices of the CSI 300 index spanning from December 2, 2024, to March 28, 2025. The model aims to enhance the accuracy, generalization capability, and fitting performance of financial stock price

prediction by synergizing CEEMDAN's decomposition-denoising functionality, BiLSTM's bidirectional feature extraction, and the attention mechanism's focus on critical Intrinsic Mode Function (IMF) components. This integration is designed to address the information complexity in financial time series, enabling more precise capture of latent patterns and nonlinear dynamics.

## 2. Relevant model

### 2.1 CEEMDAN

CEEMDAN (Complete Ensemble Empirical Mode Decomposition with Adaptive Noise) is an advanced signal decomposition technique designed for nonlinear and nonstationary signals, including vibration signals, biomedical data, and financial time series. As an optimized version of traditional EMD (Empirical Modal Decomposition) and its variants EEMD (Ensemble EMD) and CEEMD, it addresses critical limitations such as modal aliasing, noise residue, and computational inefficiency. In financial markets, high-frequency data typically contain substantial noise and exhibit strong nonlinear and nonstationary characteristics. Traditional feature extraction methods like Fourier transform struggle to capture local data structures, while linear models fail to characterize the complex dynamics of financial markets. CEEMDAN's adaptive decomposition capability enables it to break down high-frequency data into intrinsic mode function (IMF) components across diverse frequency bands based on data-driven characteristics, facilitating precise extraction of effective information. Through its noise-assisted decomposition mechanism, high-frequency noise energy is distributed across multiple IMFs, allowing for efficient noise reduction via thresholding or selective reconstruction, thereby enhancing data quality and stability. Moreover, by leveraging adaptive noise injection and staged decomposition, CEEMDAN significantly mitigates modal aliasing issues, achieving accurate modal separation and demonstrating robust performance. The algorithm's decomposition of data into interpretable IMF components also enhances model transparency, providing clear feature dimensions for subsequent analysis. As such, CEEMDAN offers a powerful solution for feature extraction and noise processing in high-frequency financial datasets.

The main decomposition process is as follows:

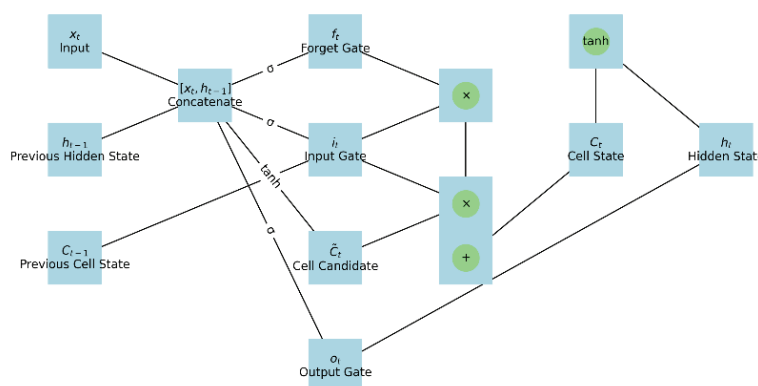
- (1) White noise  $n_0(t)$  with zero mean and standard deviation  $\sigma_0$  is added to the original signal  $x(t)$ , then,  $x_0(t) = x(t) + n_0(t)$ , which is decomposed to obtain the first Intrinsic Mode Function (IMF) with component  $c_1(t)$  and the residual component  $r_1(t)$ ;
- (2) The standard deviation  $\sigma_1$  of  $c_1(t)$  is calculated. White noise  $n_1(t)$  with zero mean and standard deviation  $\sigma_1$  is added to the residual component  $r_1(t)$ , resulting in  $x_1(t) = r_1 + n_1(t)$ . Then, EMD on  $x_1(t)$  is performed to obtain the second IMF with component  $c_2(t)$  and the new residual component  $r_2(t)$ ;
- (3) The above steps are repeated until a predefined stopping criterion is met, typically when the residual component satisfies certain stationarity conditions or a preset number of decomposition layers is reached. Finally, a series of IMF components  $c_1(t), c_2(t), \dots, c_n(t)$  and the residual component  $r_n(t)$  are obtained.

### 2.2 LSTM and BiLSTM

#### 2.2.1 Long Short-Term Memory

The LSTM (Long Short-Term Memory) model, as an advanced variant of Recurrent Neural Networks (RNNs), effectively addresses the gradient vanishing exploding issues that plague traditional RNNs when processing long sequential data.

Figure 1 Schematic of LSTM



The LSTM model primarily comprises forgetting gates, input gates, output gates, and cell states, as illustrated in Fig. 1. The forgetting gate selectively retains or discards historical state information, the input gate precisely regulates the current cell state update, and the output gate controls the transmission of internal state to the external hidden state  $h_t$ . Given the current input  $x_t$ , the final output  $h_t$  is derived through the following equations:

$$f_t = \sigma(W_f \cdot [h_{t-1}, x_t] + b_f) \quad (1)$$

$$i_t = \sigma(W_i \cdot [h_{t-1}, x_t] + b_i) \quad (2)$$

$$\tilde{C}_t = \tanh(W_c \cdot [h_{t-1}, x_t] + b_c) \quad (3)$$

$$C_t = f_t * C_{t-1} + i_t * \tilde{C}_t \quad (4)$$

$$o_t = \sigma(W_o \cdot [h_{t-1}, x_t] + b_o) \quad (5)$$

$$h_t = o_t * \tanh(C_t) \quad (6)$$

Here,  $f_t$ ,  $i_t$ , and  $o_t$  represent the forgetting gate, input gate, and output gate, respectively;  $\tilde{C}_t$  denotes the candidate cell state being updated;  $C_{t-1}$  is the previous cell state;  $\sigma$  signifies the sigmoid activation function;  $\tanh$  represents the hyperbolic tangent function;  $W_f$ ,  $W_i$ ,  $W_c$ ,  $W_o$  are weight matrices; and  $b_f$ ,  $b_i$ ,  $b_c$ ,  $b_o$  are bias terms.

However, the unidirectional architecture of LSTM exhibits inherent limitations in analyzing high-frequency data. This structure can only predict current stock prices based on historical information, failing to leverage potential influencing factors embedded in future data-yet in financial markets, the impact of future events or information on current stock prices is often non-negligible. Moreover, the unidirectional design constrains its capability to deeply excavate and extract features from complex data patterns.

### 2.2.2 Bidirectional Long Short-Term Memory

The BiLSTM model fundamentally relies on LSTM cell states to retain key information over long sequences, while enhancing its capability to capture cross-cycle features through bidirectional information flow.

In processing high-frequency stock data, BiLSTM outperforms unidirectional LSTM models significantly. Unlike LSTM, BiLSTM's bidirectional architecture overcomes the constraints of one-way information processing: it not only extracts historical trend patterns but also captures the potential influence of future events on current stock prices via backward propagation, thereby integrating temporal dependencies from both past and future contexts.

BiLSTM leverages its gating mechanisms and diverse activation functions to effectively model high-dimensional nonlinear mappings, overcoming the limitations of linear models and shallow networks to accurately characterize complex stock price fluctuations. Its forward and backward LSTM layers independently extract temporal features from opposite directions, and their integrated outputs capture comprehensive sequence context dependencies, enabling deep analysis of complex correlations in time-series data. When combined with CEEMDAN, BiLSTM further enhances noise suppression and signal pattern separation capabilities, establishing itself as a critical technical tool for stock price prediction.

### 2.3 Attention Mechanism

The attention mechanism (AM) enables automatic identification and emphasis on critical event periods. Unlike traditional LSTM models, which suffer from long-range information memory decay, AM dynamically assigns weights to strengthen associations with key historical nodes while suppressing high-frequency noise and extreme outliers, thus effectively mitigating model overfitting.

In stock closing price prediction, integrating AM with CEEMDAN and BiLSTM offers distinct advantages. When combined with CEEMDAN, AM accurately focuses on key IMF components derived from decomposition, efficiently filtering data noise, highlighting core trend information, and significantly enhancing feature extraction efficiency and signal purity in complex financial data. This strengthens the model's capability to identify price fluctuation patterns. When paired with BiLSTM, AM breaks the traditional equal-processing mode of bidirectional information by dynamically allocating time-step weights, enhancing the model's ability to capture long-range dependencies. This allows BiLSTM to more flexibly focus on critical information in stock price sequences and optimize the fusion of historical and future context.

### 2.4 Indicators for model evaluation

This paper employs the Mean Absolute Error (MAE), Mean Squared Error (MSE), and Coefficient of Determination

(R-squared) as evaluation metrics to assess the model's fitting and prediction performance. The formulations for these indices are as follows:

$$MAE = \frac{1}{n} \sum_{i=1}^n |y_i - \hat{y}_i| \quad (7)$$

$$MSE = \frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_i)^2 \quad (8)$$

$$R^2 = 1 - \frac{\sum_{i=1}^n (y_i - \hat{y}_i)^2}{\sum_{i=1}^n (y_i - \bar{y})^2} \quad (9)$$

Here,  $y_i$  denotes the true value of the  $i$ -th sample,  $\hat{y}_i$  represents the predicted value, and  $n$  is the sample size. Smaller MAE and MSE values indicate better model-data fit.  $R^2$  measures the model's explanatory power for real variations, ranging in  $[0,1]$ : the closer its value is to 1, the better the model's fitting performance.

### 3. Model Building

In this paper, CEEMDAN-AM-BiLSTM and CEEMDAN-BiLSTM-AM models are established based on BiLSTM, to predict the stock price and the model results are compared further.

(1). The univariate BiLSTM model utilizes a single historical feature column as input for prediction. Its core principle lies in modeling the temporal patterns of univariate data by capturing contextual dependencies between past and future states in the time series.

(2). The CEEMDAN-BiLSTM model incorporates preprocessing steps to enhance prediction accuracy. First, the Mann-Kendall trend test ( $p < 0.05$ ) confirmed significant trends in the data. Leveraging CEEMDAN decomposition, the original dataset was decomposed into IMFs. IMFs were then filtered through three criteria: exclusion of components with excessive volatility (indicating noise or anomalies), removal of those with negligible magnitude and predictive contribution (based on mean/variance analysis), and identification/elimination of white noise components via the Ljung-Box test. This process effectively isolated noise from underlying trends, improving signal purity. By leveraging CEEMDAN's modal decomposition, the model minimizes noise interference, enabling BiLSTM to more accurately capture temporal trends and cyclical patterns. This synergistic approach enhances the model's analytical and predictive capabilities for time-series data.

(3). The CEEMDAN-AM-BiLSTM model enhances predictive accuracy by integrating adaptive decomposition, attention weighting, and bidirectional temporal modeling. Following CEEMDAN decomposition of the original time series into IMFs, the AM prioritizes forecasting-relevant components, enabling the model to: Dynamically assign higher weights to informative IMFs to focus on key trends; Suppress noise and redundant signals via differential weighting; Optimize input representations for BiLSTM by emphasizing salient temporal patterns. This synergy among CEEMDAN's noise-filtering decomposition, AM's adaptive feature selection, and BiLSTM's bidirectional context capture strengthens the model's capability to discern complex financial trends.

(4). To address BiLSTM's memory constraints in processing long sequences, the CEEMDAN-BiLSTM-AM model introduces an attention mechanism for optimization. By computing attention weights, the model breaks the equal-processing paradigm for time-step information, enabling flexible focus on critical sequence segments, effective capture of long-range dependencies, and enhanced long-sequence processing capabilities. Additionally, the attention mechanism dynamically adjusts bidirectional contextual information weights to further optimize information fusion.

### 3.1 Data sources and pre-processing

#### 3.1.1 Data sources

The minute-level closing prices of the CSI 300 index during trading days from December 2, 2024, to March 28, 2025, were retrieved via the Tomtom financial terminal, yielding an original high-frequency dataset comprising 21,594 data points. To visually characterize the data, a line graph is plotted, as shown in Figure 2.

#### 3.1.2 Data descriptive statistical analysis.

Descriptive statistical analysis of the raw data is presented in Table 1. Results show an extreme deviation of approximately 386.62 and a standard deviation of 70.39, accounting for 1.8% of the mean. The skewness value of -0.8169 indicates a left-skewed price series with strong volatility.

Figure 2 Line graph of raw data

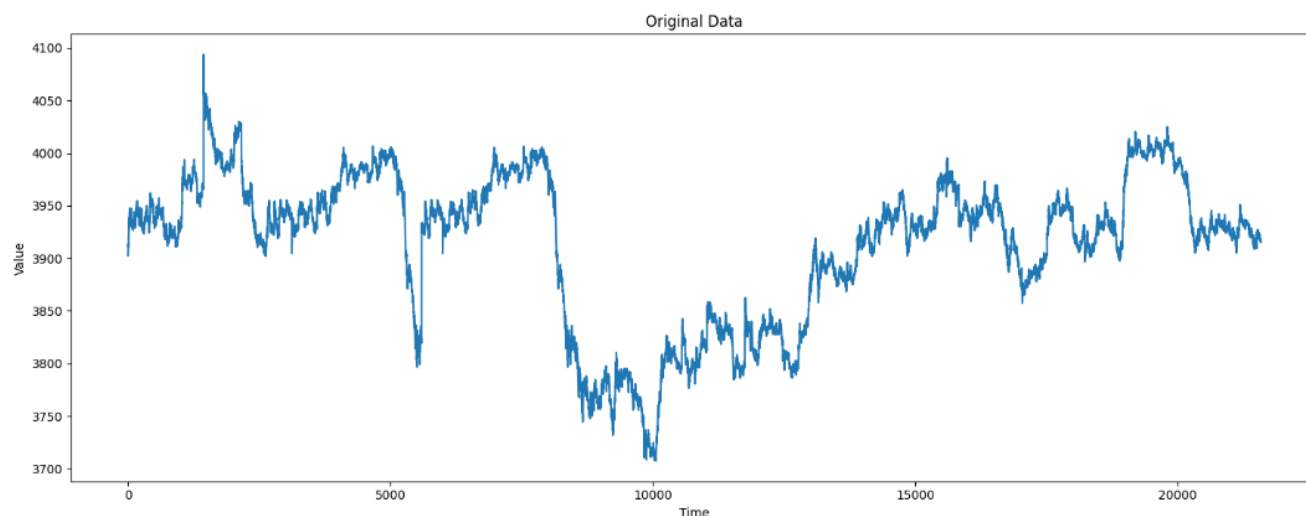


Table 1 Descriptive statistics of raw data

	volume	maximum	minimum	average	statistics	kurtosis	skewness
1-minute close	21594	4093.82	3707.20	3913.89	70.39	2.8405	-0.8169

### 3.1.3 Data pre-processing

To enhance algorithm performance and accelerate training, the data were normalized using the Z-score method to conform to a distribution with a mean of 0 and a standard deviation of 1. The normalization formula is as follows:

$$\hat{x}_t = \frac{x_t - \mu}{\sigma} \quad (10)$$

Here,  $\hat{x}_t$  denotes the normalized stock price data,  $x_t$  represents the original data prior to normalization, and  $\mu$  and  $\sigma$  signify the mean and standard deviation of the original series, respectively.

## 3.2 Empirical Research

### 3.2.1 BiLSTM model training and results analysis

The model employs a sliding window approach with a window size of 20 for data processing. The architecture consists of two layers, each containing 64 neurons, with dropout layers added to both to mitigate overfitting. The dataset is partitioned into an 80% training set and a 20% testing set. For training, the model is configured with 100 epochs and a batch size of 64. Early stopping is implemented to monitor validation set loss, terminating training if no improvement is observed for 30 consecutive epochs.

As depicted in Figure 3, the trained prediction results are visualized for analysis, where the blue line represents the original data and the orange line denotes the prediction results of the BiLSTM model. The orange curve closely aligns with the trend of the blue curve, demonstrating that the regularized model exhibits superior prediction performance.

Based on the comparison between model predictions and real values, evaluation metrics are calculated, with results presented in Table 2. For the test set error metrics: MAE of 1.2244 indicates minimal average prediction bias per sample; MSE of 2.9952 suggests strong performance in predicting extreme values; An  $R^2$  close to 1 demonstrates excellent data fit. Collectively, these metrics highlight the model's effectiveness while indicating potential for further optimization to enhance predictive performance.



Figure 3 BiLSTM Price Forecast

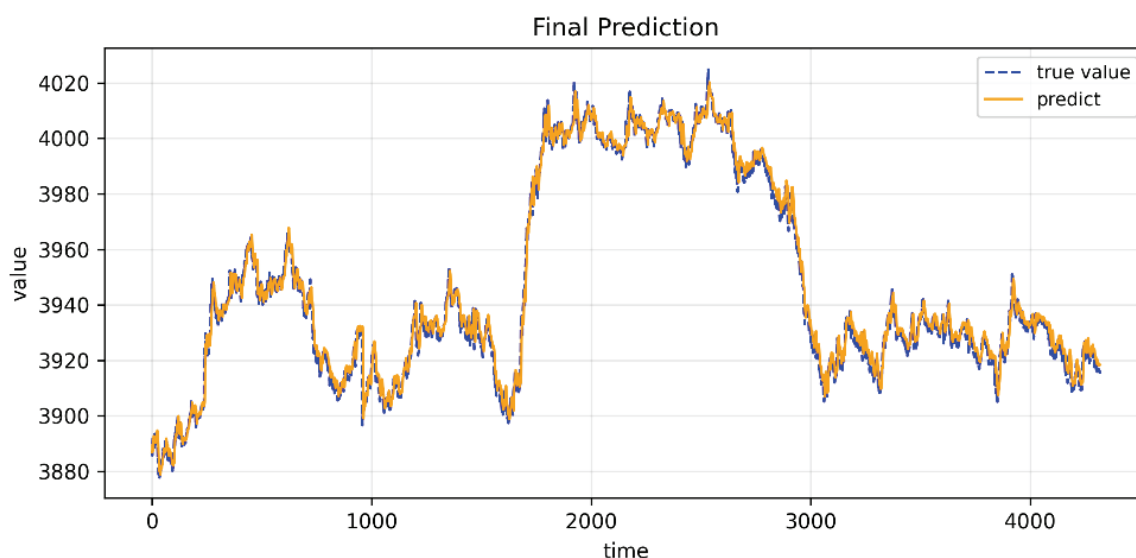


Table 2 BiLSTM model evaluation metrics

	MAE	MSE	R <sup>2</sup>
BiLSTM	1.2244	2.9952	0.9873

### 3.2.2 CEEMDAN -BiLSTM model training and result analysis

The dataset underwent CEEMDAN decomposition, with results shown in Figure 4. IMF1 was excluded due to excessive volatility, while the remaining IMFs were confirmed as non-white noise. Further analysis revealed a clear trend in IMF13, prompting the application of polynomial fitting-based on fitting coefficients—to predict its behavior.

This model configures a time step of 30 and partitions the dataset into an 8:2 training-test split. The architecture includes: First Bidirectional LSTM Layer: With 'units=64' and 'return-sequences=True', it preserves sequential outputs to connect subsequent LSTM layers. A Dropout layer (20% neuron dropout rate) is added to mitigate overfitting. Second Bidirectional LSTM Layer: Set to 'units=64' and 'return-sequences=False' to output only the final time step's result, followed by another Dropout layer for further regularization. The model is trained with 'epochs=100' and a batch size of 16.

The trained model was applied to predict the test set data, generating predicted values for each IMF component. Non-interfering terms were processed using the BiLSTM model, with results visualized in Figure 6. As shown in Figure 6, the BiLSTM model effectively predicts each IMF component, largely aligning with the general trend of actual values. Figure 7 illustrates the polynomial fitting results for IMF13, where the fitted curve broadly captures the downward trend of the actual data. This indicates the model's capability to identify IMF13's overall change pattern, though opportunities for improving the precision of detailed fitting remain. By element-wise summing all IMF predictions, the total forecast reflecting the overall trend is obtained. As shown in Figure 8, the overall trends of the two curves are highly consistent, indicating that the model's forecasts effectively fit the actual values in terms of trend. Table 3 reveals that the CEEMDAN-BiLSTM model outperforms the BiLSTM model in prediction accuracy. With an MAE of 1.0304, the CEEMDAN-BiLSTM model exhibits a reduced average deviation from true values. Its MSE of 2.1431 indicates minimized prediction result fluctuations and enhanced data fit. While both models yield high R<sup>2</sup> values, signaling a strong linear relationship between predicted and true values, the CEEMDAN-BiLSTM model's R<sup>2</sup> is closer to 1, underscoring its superior linear correlation with actual data.

Figure 4 Decomposing the IMF chart

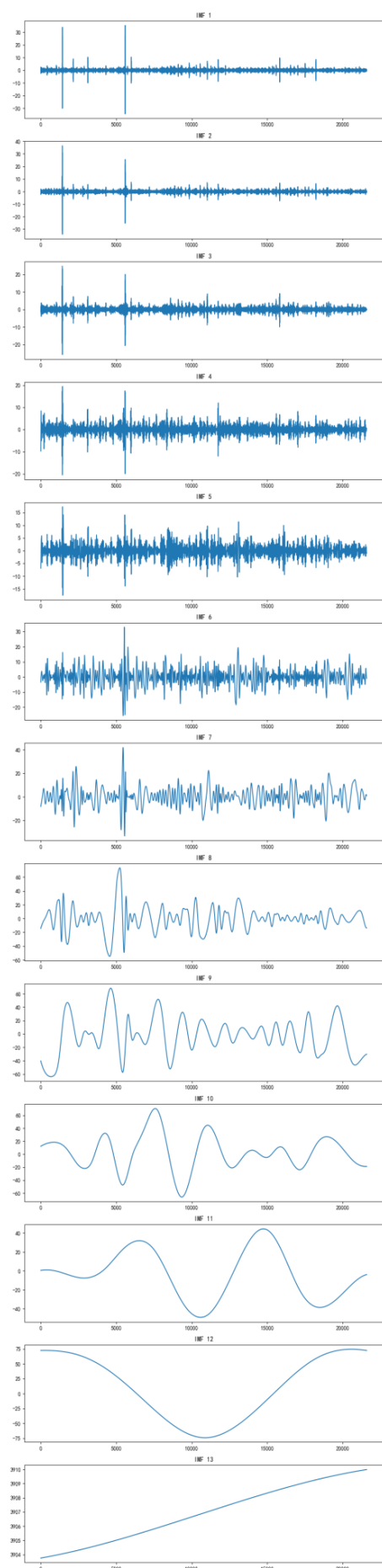


Figure 5 IMF instantaneous rate plot

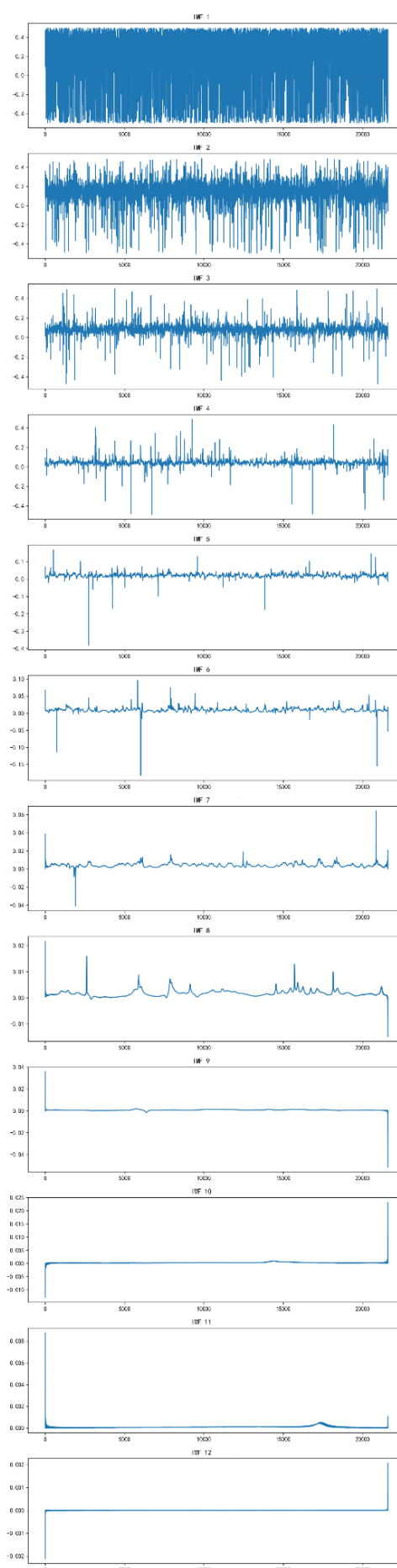


Figure 6 BiLSTM prediction IMF plot

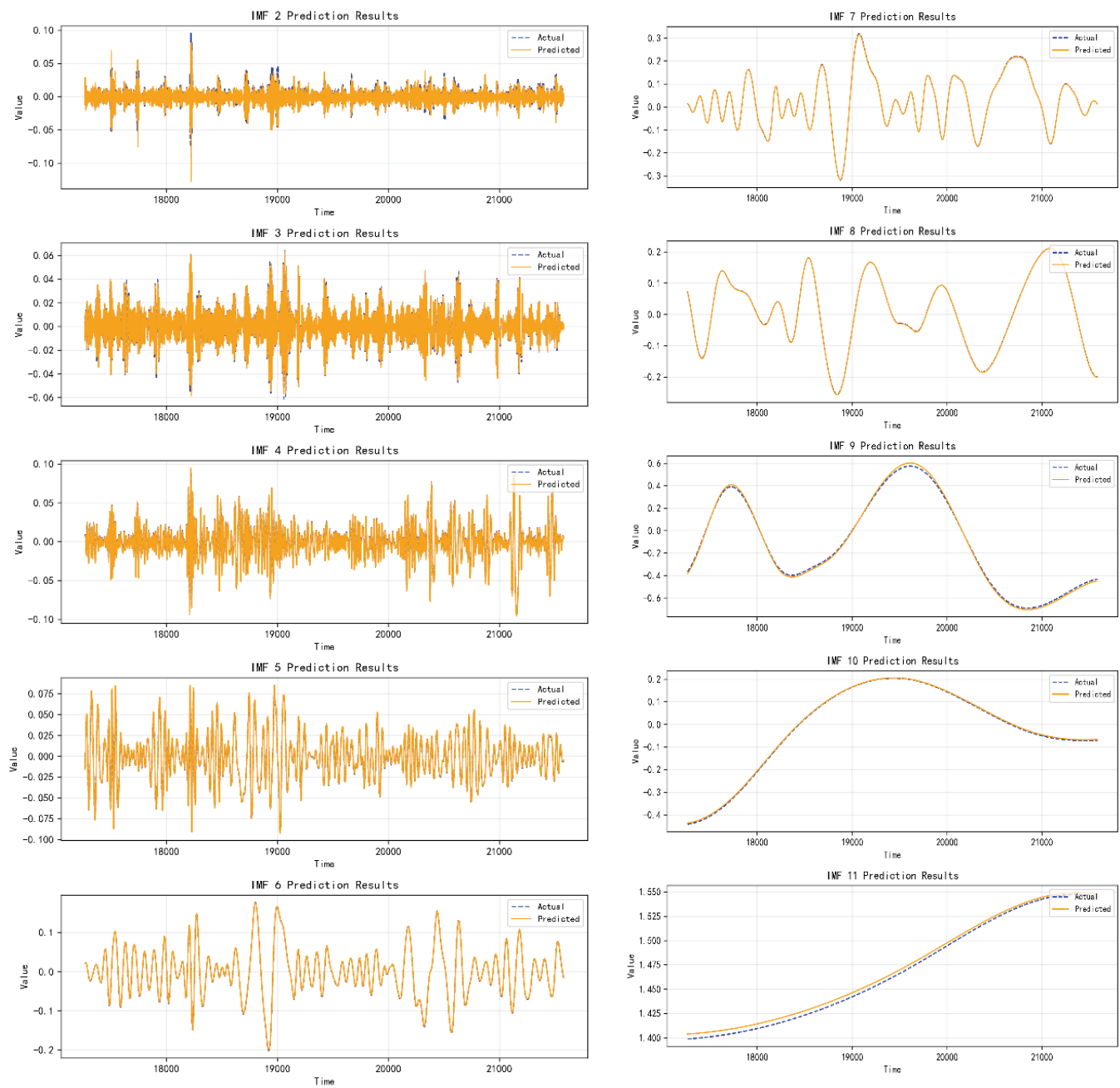


Figure 7 IMF13 polynomial fitting effects

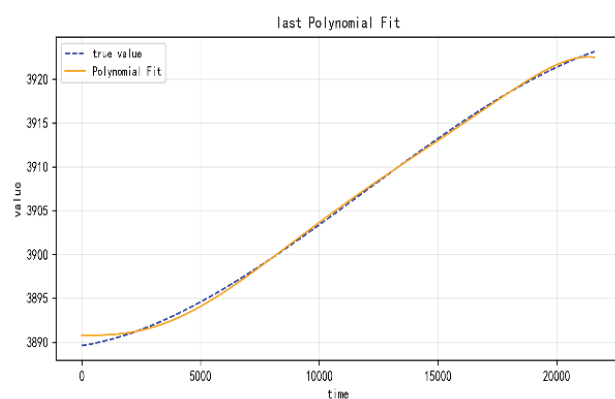


Figure 8 CEEMDAN-BiLSTM prediction effect

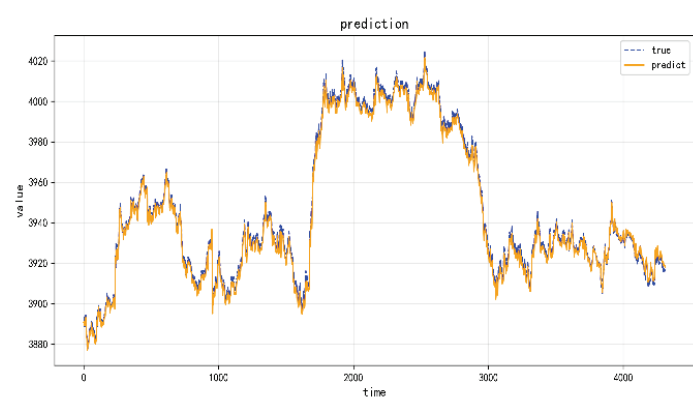


Table 3 Comparison of model evaluation indicators

	MAE	MSE	R <sup>2</sup>
BiLSTM	1.2244	2.9952	0.9873
CEEMDAN-BiLSTM	1.0304	2.1431	0.9983

### 3.2.3 Temporal Attention CEEMDAN-BiLSTM-AM Model Training and Result Analysis

The model configuration is as follows: Data Preparation: A sliding window with 'look-back=10' is applied, and the dataset is split into 80% training and 20% test sets. CEEMDAN Decomposition: Parameters set to 'noise-width=0.25' and 'trials=100'. BiLSTM Architecture: Two hidden layers each with 64 neurons, interspersed with Dropout layers ('dropout-rate=0.2'). Attention Mechanism: Integrated to dynamically weight temporal dependencies. Training Protocol: Maximum 'epochs=100', 'batch-size=32', and early stopping with validation monitoring. Post-processing: 6th-order polynomial fitting applied to the trend-dominant IMF component. Figure 9 presents the attention weight heatmap for IMF2, based on 100 test set samples with a look-back window of 10 time steps (representing the last 10 minutes). The color scale on the right indicates that lighter shades correspond to higher weights. The heatmap reveals: Temporal Focus: Lighter colors dominate the latter time steps, demonstrating the model's preference for recent stock price data. Sample-Specific Variability: Significant color differences across samples at the same time step highlight that critical moments for price movement judgment vary across periods, with certain time steps in specific samples carrying disproportionately high weights. These results indicate the model's tendency to prioritize recent trends while adapting to time-varying key influence points.

Figure 9 Heat map of IMF2 weights

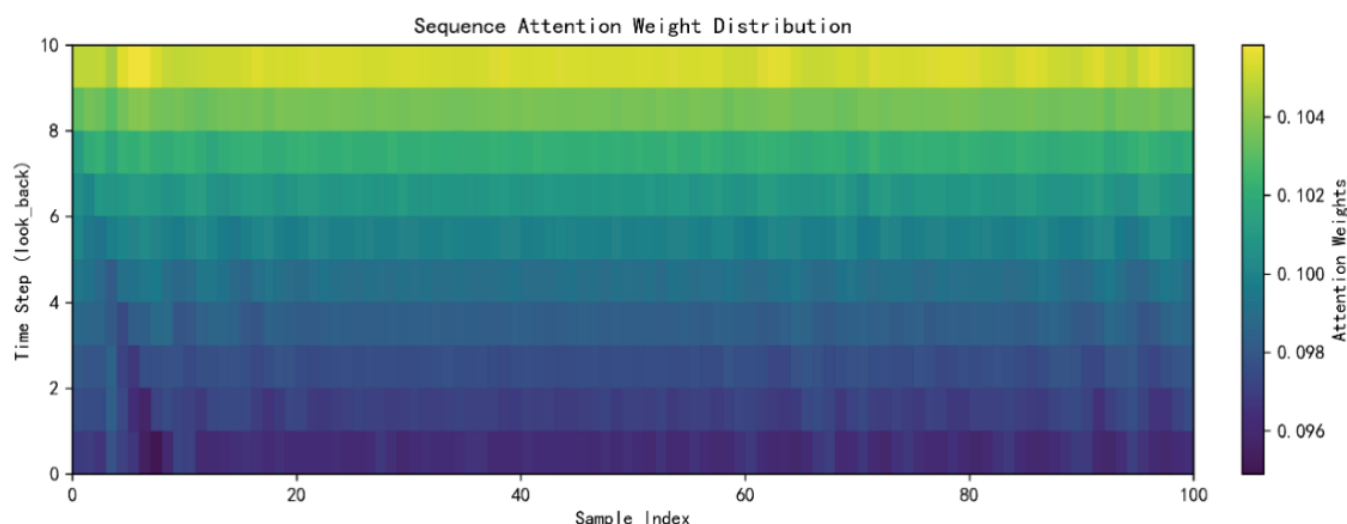


Figure 11 indicates notable biases in the model's predictions for IMF2 and IMF12. In contrast, Figure 13 demonstrates a strong polynomial fit for IMF13. Figure 14 shows that the model's total prediction curve aligns closely with the actual value curve in overall trend, effectively tracking the actual trends at peak and valley points. These results suggest that the BiLSTM model integrated with the attention mechanism can effectively capture dynamic changes in data trends.

### 3.2.4 Modal Attention CEEMDAN-AM-BiLSTM Model Training and Result Analysis

This model shares identical parameter settings with the CEEMDAN-BiLSTM-AM model, with the sole distinction being the application location of the attention mechanism. Figure 10 displays a histogram of IMF attention weights (IMF1 is excluded from prediction, and 0-11 in the figure correspond to IMF2-IMF13, respectively). Bar heights indicate that most IMFs have positive weights, with IMF6 exhibiting the highest weight, followed by significant contributions from IMF9 and IMF4. Notably, IMF2 carries a negative weight, representing market volatility components the model "discounts." Tests show that removing negatively weighted IMFs does not enhance forecasting performance, so they are retained to preserve data integrity.

Figure 10 IMF weighting chart

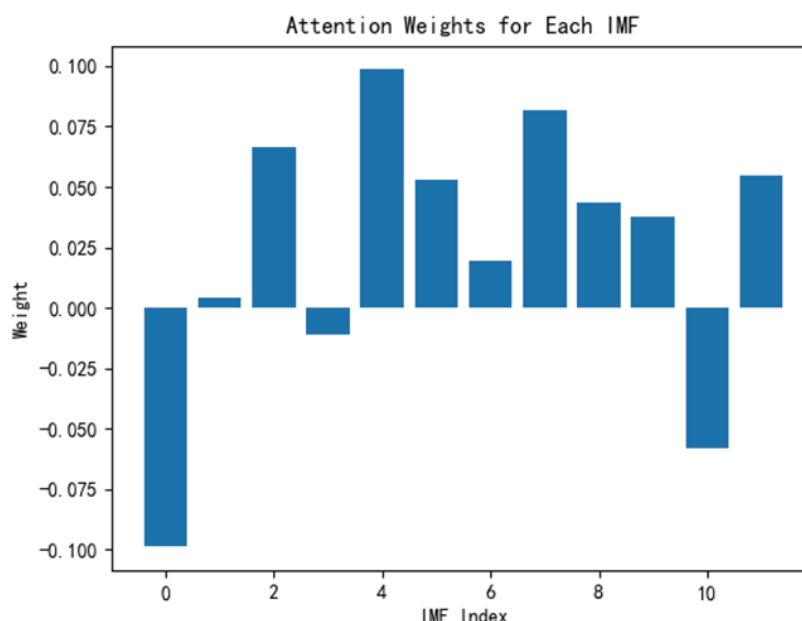


Figure 12 demonstrates the model's superior performance in predicting individual IMF components. Figure 15 highlights a strong polynomial fit for IMF13, while Figure 16 shows that the model's total prediction curve closely aligns with the overall trend of the actual data. Specifically: In the 0-2000 horizontal axis range, both curves exhibit upward-then-downward fluctuations; In the 2000-3000 range, both curves show synchronized and significant downward trends.

These results indicate that integrating the attention mechanism at the CEEMDAN decomposition layer enables the model to effectively capture the data's overall trend. Collectively, this mechanism enhances the model's capability to discern data trends and fluctuations by filtering key IMF components and eliminating redundant information, thereby improving the efficiency of time-series feature extraction.

### 3.3 Analysis of results

Based on the model, evaluation metrics are calculated and presented in Table 4. Results show that incorporating the attention mechanism into CEEMDAN-BiLSTM significantly improves MAE, MSE, and  $R^2$ , demonstrating enhanced model performance. When comparing attention mechanism placements (CEEMDAN decomposition layer vs. BiLSTM layer), modal attention achieves an MAE of 0.2828, which is lower than temporal attention-indicating superior control over the average absolute deviation between predicted and actual values, thus reflecting higher prediction accuracy. In terms of MSE, modal attention achieves a value of 0.1422, smaller than that of temporal attention, indicating that the model under modal attention handles errors more effectively, with a smaller mean squared deviation between predicted and actual values, reflecting higher accuracy. Regarding  $R^2$ , both values are very close to 1, with modal attention reaching 0.9998, which slightly higher than temporal attention signifying a marginal advantage in data fitting, though the difference between the two is negligible.

In summary, integrating the attention mechanism into the CEEMDAN-BiLSTM framework significantly enhances model performance for both modal and temporal attention variants. Among them, the modal attention mechanism demonstrates more prominent improvements in reducing prediction errors and enhancing goodness-of-fit, enabling more accurate predictions compared to the temporal attention mechanism and the original CEEMDAN-BiLSTM model.

Table 4 Comparison of model evaluation indicators

	MAE	MSE	R
BiLSTM	1.2244	2.9952	0.9873
CEEMDAN-BiLSTM	1.0304	2.1431	0.9983
CEEMDAN-AM-BiLSTM	0.2828	0.1422	0.9998
CEEMDAN-BiLSTM-AM	0.4450	0.2860	0.9997

Figure 11 C-B-A Forecast chart

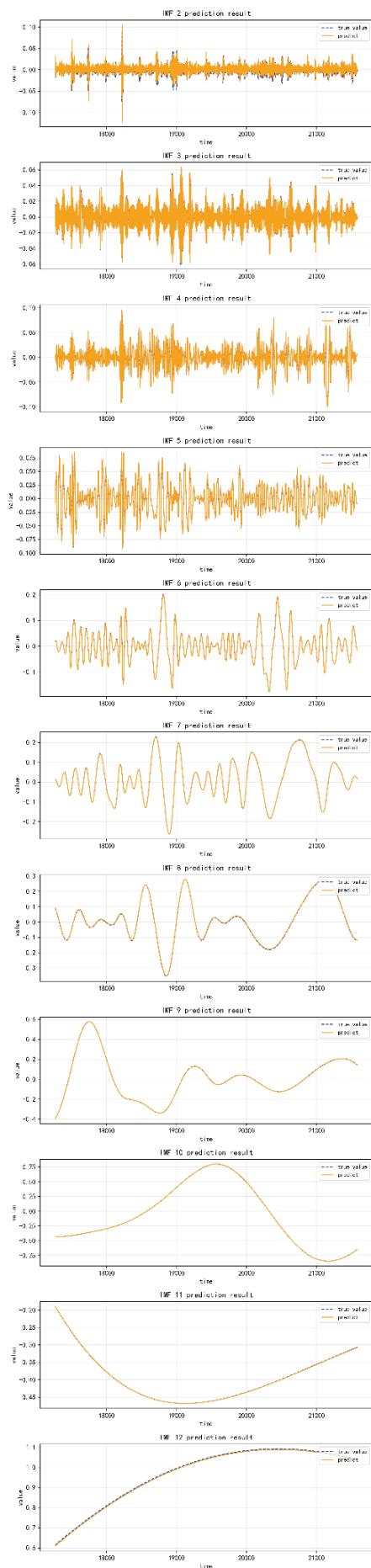


Figure 12 C-A-B Forecast Chart

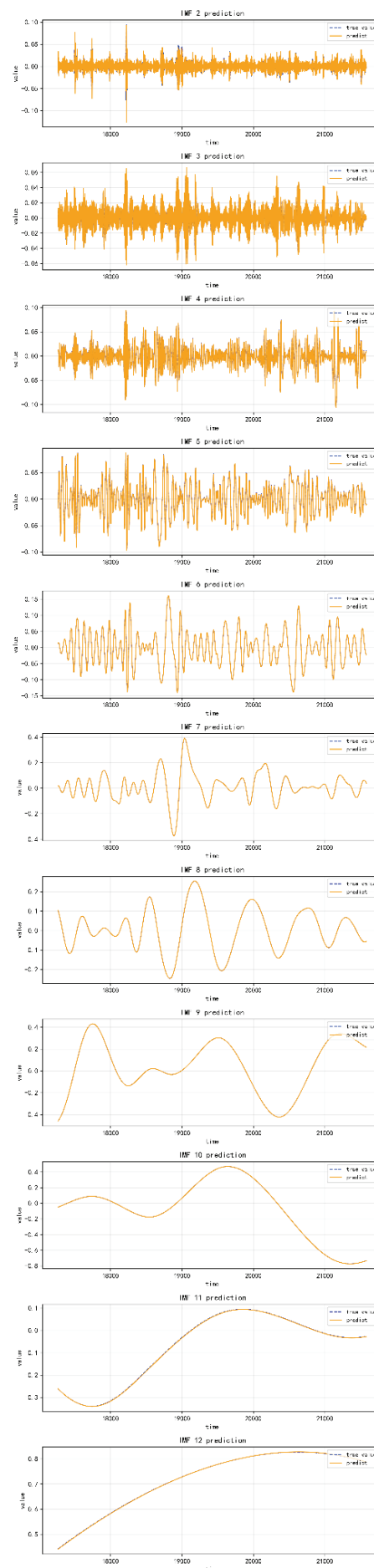




Figure 13 C-B-A IMF13 projection chart

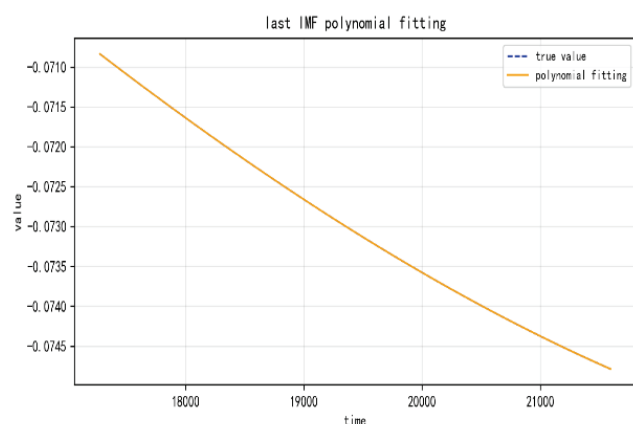


Figure 14 C-B-A General Forecast Map

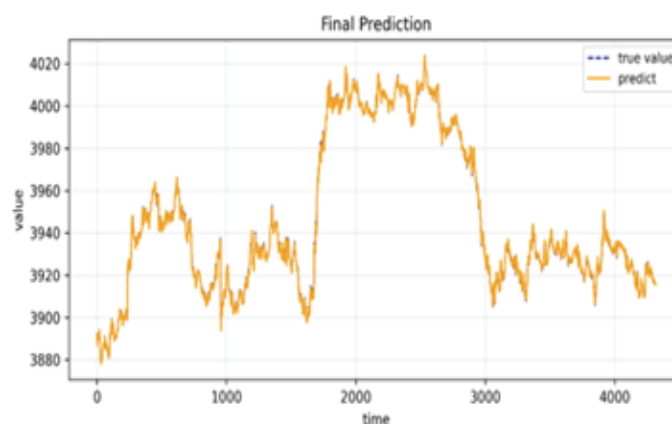


Figure 15 C-A-B IMF13 projection chart

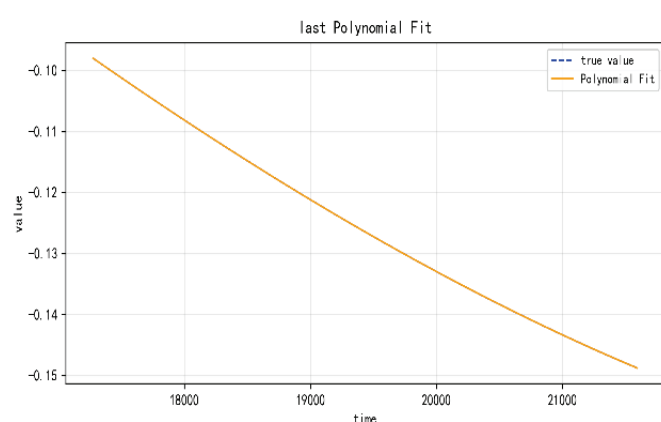


Figure 16 C-A-B General Forecast Map



## 4. Summaries

To address high-frequency sequence prediction challenges, we propose a novel CEEMDAN-AM-BiLSTM hybrid model. The framework integrates CEEMDAN, BiLSTM networks, and AM. Key steps include: Multi-scale Decomposition: CEEMDAN decomposes the original sequence into Intrinsic Mode Functions (IMFs), reducing noise and extracting multi-scale features. Bidirectional Temporal Learning: BiLSTM networks capture bidirectional temporal dependencies within each IMF component. Dynamic Feature Weighting: An attention mechanism dynamically assigns weights to IMF components, prioritizing key features and filtering redundant information. This hybrid approach effectively addresses limitations of traditional models in financial time-series analysis, achieving efficient integration of financial data characteristics and enhancing predictive accuracy.

Empirical results demonstrate that the hybrid model outperforms the traditional BiLSTM model across multiple evaluation metrics, significantly reducing prediction errors and validating the effectiveness of algorithmic advantage complementarity. However, the study has two notable limitations requiring improvement: Neglected Transaction Costs: In high-frequency trading scenarios, the model focuses solely on price trend prediction without incorporating transaction costs (e.g., commissions, stamp duties, slippage costs) into the modeling framework. This omission may cause discrepancies between predicted results and actual trading returns, potentially undermining the validity of investment decisions. Suboptimal Hyperparameter Tuning: The model's hyperparameter optimization relies primarily on manual trial-and-error adjustments, lacking systematic and global optimization. It fails to leverage intelligent algorithms such as Particle Swarm Optimization (PSO), Grid Search, or Bayesian Optimization for automatic parameter tuning, preventing the model from achieving its optimal performance state.

To address the above limitations, future research could explore the following directions: Integration of Transaction Costs: Develop a "prediction-cost" joint optimization model by incorporating transaction cost functions (e.g., commissions,

slippage) into the objective function or constraints. This would enable a balance between prediction accuracy and trading revenue, enhancing the model's applicability to real-world high-frequency trading scenarios. Intelligent Hyperparameter Optimization: Employ global optimization algorithms (e.g., Particle Swarm Optimization, Bayesian Optimization) to systematically tune hyperparameters. Additionally, integrating reinforcement learning or evolutionary algorithms could dynamically adjust model structures and parameters, further improving adaptive capacity and predictive performance. These advancements would strengthen the hybrid model's practical utility in financial markets.

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## Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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# Analysis of Financial Fraud and Governance in Guangyuyuan

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**Abstract:** In recent years, with the rapid development of the capital market, cases of financial fraud by listed companies have gradually increased, leading to increasingly severe economic consequences. This study takes Guangyuyuan Chinese Medicine Co., Ltd. as the research subject, thoroughly analyzing its methods and motivations for financial fraud, and derives corresponding preventive measures based on this case. The aim of this research is to provide references and insights for the prevention and governance of financial fraud in listed companies.

**Keywords:** Financial Fraud; Fraud Triangle Theory; Preventive Measures

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## 1.Introduction

Over the years, there have been an increasing number of financial fraud cases in China's securities market, and the pharmaceutical manufacturing industry is one of the hardest hit areas for financial fraud. Although the country has introduced many relevant laws, this phenomenon still persists despite repeated bans. This paper takes Guangyuyuan Traditional Chinese Medicine Co., Ltd. as the research object, and analyzes the reasons and methods of financial fraud in Guangyuyuan to find better prevention and control measures for such fraud cases. This study can serve as a warning to companies with fraudulent ideas, and also provide suggestions for others on measures to prevent financial fraud<sup>[1]</sup>.

## 2.Analysis of Financial Fraud Methods in Er Guang Yu Yuan

### 2.1 Abuse of income recognition policy

From 2016 to 2021, Guangyu Yuan's annual report disclosed information about the "buyout sales" model that did not match its actual operation. The real situation at that time was that its subsidiary, Shanxi Guangyuyuan National Pharmaceutical Co., Ltd., signed agreements with multiple downstream distributors with clauses stating that "products can be returned unconditionally if they are unsold or on time", improperly utilizing the accounting policy of "recognizing revenue upon delivery", and thus recognizing sales revenue in advance. Due to the existence of return or repurchase agreements, the essence of such transactions is not actual sales, but rather a storage behavior of placing goods at distributors for consignment sales<sup>[2]</sup>. Therefore, it cannot be considered as having generated sales revenue. However, the finance department of Shanxi Guangyuyuan still considers the outflow of goods as revenue, resulting in the company's cumulative inflated revenue of approximately 674 million yuan.

### 2.2 Improper handling of sales expenses

In order to cover up the discrepancies in accounts caused by inflated income, Guangyuyuan also has certain problems in handling sales expenses. Specifically, the attribution period of some sales expenses is inaccurate, or their accounting treatment

does not strictly comply with the relevant provisions of the Enterprise Accounting Standards. For example, by including expenses that should have been attributed to subsequent years in the current period in advance, in order to cover up the fraudulent behavior of recognizing income in advance, this further leads to the distortion of financial data<sup>[3]</sup>.

### **3. Analysis of the Reasons for Financial Fraud in San Guang Yu Yuan**

In order to better analyze the reasons for financial fraud in Guangyuyuan, this article will analyze this case based on the fraud triangle theory from the three factors of pressure, opportunity, and self rationalization.

#### **3.1 Stress factors**

The pressure factor is considered a prerequisite for the occurrence of fraudulent behavior, that is, the motivation for fraudsters to decide to commit financial fraud. In 2016, Guangyuyuan completed the acquisition of 40% equity of Shanxi Guangyuyuan held by its controlling shareholder Dongsheng Group and others. At that time, the transaction price for the 40% equity of Shanxi Guangyuyuan was as high as 1.292 billion yuan. However, by the end of 2015, the net assets of Shanxi Guangyuyuan were only 26 million yuan. One of the counterparties in this major asset restructuring was Dongsheng Group, the controlling shareholder of Guangyuyuan at that time<sup>[4]</sup>. Therefore, as the party selling assets and the beneficiary of this high premium transaction, Dongsheng Group has made strict performance commitments: Dongsheng Group promises that Shanxi Guangyuyuan will achieve non recurring net profits of no less than 133 million yuan, 235 million yuan, and 433 million yuan in 2016, 2017, and 2018, respectively. During the performance commitment period, if the actual profit does not meet the standard, Dongsheng Group needs to compensate. However, Shanxi Guangyuyuan's non recurring net profit in 2015 was only 9.7373 million yuan, which undoubtedly brought huge short-term performance pressure to the management. When the actual operation fails to achieve the promised goals, in order to avoid triggering compensation clauses or legal disputes, the management decides to achieve the commitment through financial fraud<sup>[5]</sup>.

#### **3.2 Opportunity factors**

The opportunity factor is usually considered an important condition for the occurrence of fraudulent behavior, that is, whether the fraudster can commit fraud. The internal equity structure of Guangyuyuan is relatively concentrated, with Dongsheng Group holding a share of 19.46% in 2016, ranking as the largest shareholder of Guangyuyuan. Guo Jiaxue holds 72.74% of the equity of Dongsheng Group, making him the ultimate actual controller of Guangyuyuan. This equity structure allows Guo Jiaxue to hold absolute management power over the enterprise, and he can easily appoint loyal directors and executives. This makes the board of directors no longer a decision-making and supervisory body representing the interests of all shareholders, but a "rubber stamp" for executing the will of controlling shareholders, making these power departments unable to exercise their own power, have no substantive role, and are like a mere formality.

In addition to internal reasons within the company, there are also some external factors. At that time, Lianda Accounting Firm, which provided annual audit services for Shanxi Guangyuyuan, did not effectively fulfill its job responsibilities and did not play an external regulatory role. For example, the accounting firm did not correct Guangyuyuan's "buyout sales" and abuse of the accounting policy of "recognizing revenue upon delivery", and ignored obvious financial abnormal signals such as the sharp increase in sales expenses and abnormal extension of accounts receivable turnover days in Shanxi Guangyuyuan. Although we are not sure whether it is due to the insufficient ability of the certified public accountant responsible for the audit business of the company or the existence of a relationship of interest between them, Lianda Certified Public Accountants should bear some responsibility for the fact that Guangyuyuan's financial fraud was not audited.

#### **3.3 Self rationalization factors**

The self rationalization factor, often referred to as the excuse factor, played a crucial role in this case. At that time, the company was facing the dilemma of difficult to fulfill performance commitments, and there were objective conditions within the company that could lead to fraud. The management began to self persuade and find reasonable reasons for improper behavior. They mainly justify themselves based on the following two points: firstly, if financial fraud is not discovered, Shanxi Guangyuyuan will be able to smoothly fulfill performance commitments, thereby increasing the company's profits, and the stock price will also rise, bringing higher profits to the company; Secondly, there are many companies involved in financial fraud every year, and not all cases will be exposed. Even if discovered, the relevant penalties will not be very severe.

Overall, the management believes that the potential benefits of fraud not being exposed far outweigh the potential risks and costs. Under this psychological drive, the enterprise ultimately completed the process of self rationalization and took risks, leading to the occurrence of financial fraud in Guangyuyuan<sup>[6]</sup>.

## **4.Prevention and control measures for financial fraud cases in Siguang Yuyuan**

### **4.1 Improve internal governance structure**

Firstly, the equity structure should be improved. Currently, many listed companies have a highly concentrated situation of “one dominant shareholder” in terms of equity. Therefore, in order to improve the internal governance structure of the company, the top priority is to diversify the shareholding ratio of major shareholders, form effective equity checks and balances, and create a fair internal environment. Next is to ensure that governance institutions such as the shareholders’ meeting, board of directors, and supervisory board can operate independently and play their roles, so that they can mutually constrain and supervise each other, thereby avoiding the occurrence of financial fraud.

Secondly, we need to improve the system of the board of directors. The board of directors is the decision-making body for a company’s operations. If the board of directors cannot be independent of shareholders and management, it is difficult to have independent and objective judgment. However, currently, the board of directors in Chinese companies rarely plays a supervisory role. Therefore, it is necessary to improve the system of the board of directors, enhance the professional ability and level of the board of directors, prevent the management from harming the interests of shareholders in order to obtain higher benefits, supervise the behavior of the management, and prevent various interferences of shareholders in the decision-making of the management, so as to avoid the occurrence of financial fraud.

Finally, we need to improve the system of the supervisory board. The supervisory board is the internal supervisory body of the company. If the supervisory board wants to truly play its supervisory role, it must ensure that the members of the supervisory board are elected reasonably, legally, fairly and justly by the shareholders’ meeting and the company’s employees. Only when the supervisory board has real power and is not controlled by directors or senior management can it better play its role in review and supervision, thereby reducing the occurrence of fraudulent behavior.

### **4.2 Improve the system of external audit institutions**

In the financial fraud case of Guangyuyuan, Lianda Accounting Firm bears some responsibility. If the firm gives an unqualified audit opinion, it means that the registered accountant’s professional ability of the firm is insufficient or there is an interest relationship between the firm and Guangyuyuan. In order to reduce the opportunity factors brought by external factors for financial fraud in enterprises, we can take the following measures.

Firstly, external audit firms can adopt an audit rotation system, which stipulates that accounting firms cannot provide services to the same client for more than two years or for a specific period of time. By regularly changing audit firms, external audit firms can be better made independent of the audited entity, directly reducing the risk of collusion between both parties from a systemic perspective, and ensuring the objectivity and fairness of audit work.

Secondly, a third-party payment system can be established, which stipulates that the audit fees of the audited entity shall be uniformly paid to the special account of the China Securities Regulatory Commission, and then the designated audit institution appointed by the China Securities Regulatory Commission shall provide audit services to the audited entity. This can ensure that there is no direct economic interest relationship between the audited entity and the external auditing agency, to a certain extent, reducing the risk of joint fraud from the source, and ensuring the objectivity and fairness of the audit work.

### **4.3 Strengthen punishment**

From the analysis of the above methods, we can see that Guangyuyuan committed a huge amount of fraud, up to 674 million yuan, but the company only faced a fine of 8 million yuan. The huge gap between these two figures makes the punishment seem powerless. If stricter punishment mechanisms are not established, it is likely that more business managers will choose to engage in fraudulent activities in order to attract more investors and obtain higher profits. We can consider it from the following aspects:

At the legal level, for those involved in financial fraud, the amount of fines can be significantly increased, and penalties can be introduced to increase the cost of financial fraud and create a greater deterrent effect on potential offenders; At the

administrative level, for certain enterprises or individuals who seriously violate industry regulations, their licenses or business licenses may be revoked, making it impossible for them to continue engaging in related business.

## 5. Conclusions and Implications

China's securities market was established in 1986. Compared with some developed countries, China's securities market started relatively late, which has led to the insufficient function and role of the securities market. As a result, many enterprises ignore the laws and regulations of the securities market and continue to engage in financial fraud. In order to prevent this situation from happening, we should find preventive measures from different perspectives, fully play the supervisory role, and prevent or reduce the occurrence of such cases from the source. The research object of this article is Guangyuyuan Traditional Chinese Medicine Co., Ltd., and prevention and control measures are proposed for the fraudulent methods used in this case. These prevention and control measures may not be applicable to every enterprise that engages in financial fraud, but there are some suggestions for prevention and control measures such as improving internal governance structure that can provide inspiration for other listed companies. At the same time, it is believed that improving the system of external audit institutions and increasing punishment measures can also provide some ideas for the supervision department of the securities market to curb such behavior, in order to provide reference for the healthy and orderly development of Chinese enterprises.

## Funding

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## Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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# Research on Systematic Supplier Relationship Management Strategies

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**Abstract:** Against the backdrop of globalization and increasingly fierce market competition, supplier relationship management (SRM) is crucial for enterprises to acquire high-quality resources within the supply chain and enhance competitiveness. By analyzing the systematic stages of SRM—namely supplier relationship initiation, development, and maintenance—along with their key components, which include supplier evaluation and selection, supplier development, and supplier monitoring, this study proposes management strategies aimed at optimizing the SRM process and deepening inter-firm relationships between upstream and downstream enterprises. Consequently, enterprises can better execute supplier management, improve market competitiveness, and maintain a leading position in an ever-changing market environment.

**Keywords:** Supplier Relationship Management; Key Stages; Behavioral Strategies

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## 1.Introduction

The resource-based view suggests that unique and heterogeneous value resources are the source of a firm's competitive advantage. To acquire and sustain this advantage, firms often need to continuously obtain complementary value resources from external sources. When facing uncertain environments, firms must better mobilize network resources to create competitive advantages<sup>[1]</sup>. Compared with collaborating with other stakeholders, upstream suppliers of manufacturing firms possess higher specialization, are more familiar with the processes and management models of downstream manufacturers<sup>[2]</sup>, and can provide creative solutions that meet customer needs when participating in collaborative innovation tasks with downstream firms, thereby creating value<sup>[3]</sup>. Therefore, attracting suppliers with high-quality resources to participate in collaborative tasks is key for manufacturing firms to gain a competitive advantage.

Suppliers gain an exclusive advantage by being at the forefront of particular technology areas and may not be interested in providing core innovation resources to firms after an evaluation<sup>[4]</sup>, suppliers are not always able to substantially participate in the collaborative tasks of the enterprise. Although firms can rely on selection capability to mitigate this effect<sup>[5]</sup>, it is unlikely to obtain deep resource support in ordinary supply relationships. Access to core resources relies on developing close relationship interactions with suppliers<sup>[6]</sup>. Existing studies point to the key roles of buyer-supplier relationship; whether to move in the desired direction depends on whether the firm takes proactive supplier relationship management (SRM) actions. Firms can act as a central point to proactively guide the direction of their relationships with suppliers, helping them achieve their resource goals by building stable, long-lasting, and positive relationships<sup>[7]</sup>. Although the critical role of supplier relationship

management (SRM) is widely acknowledged, existing research predominantly examines SRM as an integrated whole or focuses on isolated practices—such as supplier involvement, specific asset investment, or supplier evaluation—and their impact on guiding bilateral relationships. This approach overlooks the systemic nature of SRM as an orchestrated process. How firms can implement systematic SRM activities to substantively engage suppliers in collaborative tasks remains a subject requiring further investigation.

This paper conceptualizes supplier relationship management as a multi-stage, systematic management activity. By analyzing its different stages and key components, and proposing corresponding strategies, it aims to assist enterprises in optimizing supplier relationships, acquiring high-quality resources from suppliers, and enhancing operational efficiency and market competitiveness.

## 2. supplier relationship management

Supplier Relationship Management (SRM) refers to the proactive practice through which a firm intervenes in the formation and development of its relationships with suppliers, integrating their divergent goals and strategies, with the aim of generating resource advantages by establishing and sustaining long-term, highly committed, and collaborative partnerships. By strengthening cooperation and communication with suppliers and pursuing continuous improvement through SRM, a firm can build stable, long-term collaborative relationships with its suppliers. This enables both parties to jointly respond to market changes and challenges, thereby reducing costs, improving quality, and enhancing the flexibility and responsiveness of the supply chain. Relevant studies have explored different aspects of SRM, which primarily include the following three processes: actively initiating relationships with suppliers (relationship initiation), guiding the development of the relationship in a direction consistent with the firm's strategic plans and objectives (relationship development), and identifying the direction of the relationship and making timely corrections to deviations (relationship maintenance)<sup>[8]</sup>. Our research believes that SRM with a system nature presents opportunities for firms. It is necessary to interpret SRM from a system perspective to overcome the drawbacks caused by single-level relationship behavior while enabling the healthy development of firm supplier relationship. The study summarizes the key concepts and connotations of SRM (Table 1), and provides a systematic view of how firms can develop SRM to obtain supplier innovation contribution. We adopt the core view of Yang (2023) that SRM includes relationship initiation, development, and maintenance<sup>[8]</sup>. Relationship initiation ensures supplier-firm fit, while relationship maintenance provides an efficient relationship safeguard mechanism. We predict that these three dimensions are interrelated and covariant, effectively balancing or overcoming the possible risks associated with relationship investment.

Table 1

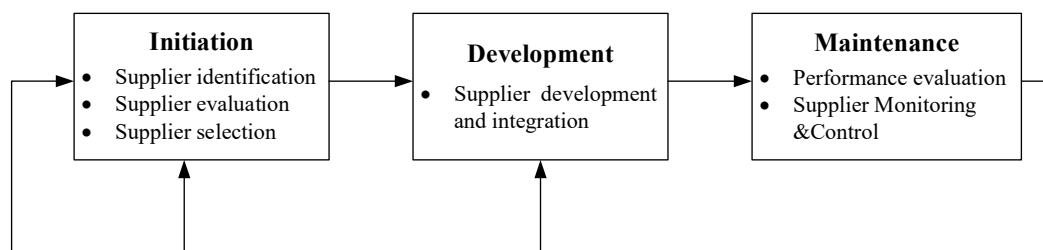
Supplier Relationship Management (SRM)	Concepts
Wagner and Johnson (2004)[9]	In the context of classical strategic management processes, SRM is considered the design, development and maintenance of supplier portfolios and supplier relationships. The ultimate goal is to integrate the resources and advantages of the buyer and the supplier to realize mutual benefits.
Miocevic and Crnjak-Karanovic (2012)[10]	SRM is a systematic process by which a firm proactively manages relationships with key suppliers to obtain resources, including relationship planning, relationship implementation, and relationship control.
Glock et al.(2017)[11]	SRM is concerned with strategically planning and managing all interactions between a buying company and its suppliers.
Yang et al.(2023)[8]	SRM is a process by which firms actively take measures to ensure positive relationships, increasing and enhancing the value of their relationships with suppliers.

The establishment of supplier relationships reflects the firm's proactive behavior in seeking cooperative suppliers, differentiating and adjusting these relationships according to its strategic objectives. This involves actions such as supplier selection and categorization to build connections with suppliers. The development of supplier relationships reflects the firm's efforts to consolidate the foundation of these relationships and actively steer their direction, for instance, by establishing long-term partnerships and effective communication channels. The maintenance of supplier relationships reflects the firm's

monitoring and corrective actions regarding these ties, such as implementing error-identification processes.

Supplier relationship initiation reflects the behavior of the firm that is actively seeking cooperative suppliers and differentiating and adapting its relationships with suppliers through actions such as selecting suppliers and classifying supplier relationships according to the firm's strategic objectives. Supplier relationship development reflects the behavior of a firm intended to consolidate the base of its relationship with suppliers and proactively guide the direction of its relationships with suppliers, and it includes, for example, establishing long-term cooperation and effective communication channels. Supplier relationship maintenance reflects a firm's monitoring and corrective actions related to its relationships with suppliers, such as establishing error identification processes. Essentially, supplier relationship initiation and maintenance provide safeguards for the firm before and after the relationship is established, respectively. Supplier relationship initiation ensures that firms properly screen their core suppliers that are strategic to achieving innovation excellence and initiate relationships with them. Supplier relationship maintenance comes into play after such a relationship has been established, and continuous relationship monitoring and corrective action can ensure that the relationship with the supplier moves in the desired direction. This effectively reduces risk and helps firms sustain access to supplier innovation resources. Supplier development provides an explanation and justification for a range of relationship management measurements and is a central part of building healthy firm-supplier relationships. Relationship initiation primarily involves the identification, evaluation, and selection of suppliers. The core of relationship development lies in supplier development—enhancing suppliers' capabilities and performance to meet buyer requirements and improve the quality of the bilateral relationship. The key to relationship maintenance is the continuous monitoring of the relationship between both parties. The SRM process of stages and practical behaviors are shown in Figure 1.

Figure 1



### 3. Key stages and behavioral strategies of supplier relationship management

#### 3.1 supplier relationship initiation

Supplier selection is the first step in initiating supplier relationships. When selecting suppliers, enterprises need to consider multiple factors, including price, quality, delivery time, service level, as well as supplier qualifications and financial stability. The criteria for supplier selection should align with the enterprise's strategic objectives. Once suppliers are chosen, the enterprise needs to manage supplier relationships through contract management, communication and coordination, and regular evaluations. Based on its own needs and market conditions, the enterprise must assess potential suppliers' qualifications, capabilities, price, quality, and delivery performance. This process typically involves a comprehensive evaluation of the supplier's financial stability, production capacity, technological capabilities, and service level. In supply chain management, supplier evaluation is a crucial link for ensuring operational efficiency and product quality. Evaluation criteria should be clearly defined to ensure that selected suppliers can meet the enterprise's specific needs. Effective supplier evaluation not only ensures supply chain stability but also promotes continuous improvement and innovation among suppliers. This process involves a thorough review of potential and existing suppliers to determine whether they meet the enterprise's standards and requirements. The following are the main strategies for supplier evaluation.

##### 3.1.1 Evaluation Criteria

Supplier evaluation is typically based on a set of established criteria, including price, quality, delivery, service, and the supplier's financial stability. Price competitiveness is a fundamental consideration, but it is not the sole factor. Quality control ensures products meet specification requirements, while ontime delivery directly impacts production schedules and

customer satisfaction. Service level reflects the supplier's responsiveness to customer needs and efficiency in problemsolving. Assessment of financial stability relates to the supplier's ability to sustain longterm cooperation.

### 3.1.2 Evaluation Process

The evaluation process typically begins with an initial screening based on the supplier's qualification documents and historical performance. Subsequently, onsite audits or desk reviews are conducted to further verify the supplier's actual operational conditions. This stage may include inspections of production facilities, quality management systems, and supply chain processes. In addition, interviews with key personnel from the supplier serve as an important step in assessing their willingness and capability to cooperate.

## 3.2 Supplier Relationship Development

Supplier Relationship Development refers to a series of supplier relationship management practices through which a company actively consolidates and develops the foundation of its relationships with suppliers and guides the direction of these relationships<sup>[12]</sup>. Supplier development is the core component of supplier relationship development. It involves the buyer implementing specific relational behaviors to enhance the supplier's capabilities and performance, thereby further unlocking relational value and enabling the supplier to better meet the needs of the manufacturing enterprise. Sometimes firms conclude that existing supplier portfolios, supplier performance and relations cannot meet strategic goals and future needs. Options for managing this depend on the situational factors surrounding the sourced item with the two extremes essentially involve changing, that is, terminating the current relationship and seeking another, or absorbing the problem supplier (vertical integration)<sup>[9]</sup>. These extreme actions offer little satisfaction and often simply are nonviable. The notion of supplier development provides a meaningful alternative

Relevant research has classified the practical forms of supplier development. For instance, Krause et al. systematically divided supplier relationship development into four major categories: resource investment in suppliers, supplier evaluation, supplier competition, and supplier incentives<sup>[13]</sup>. Benton et al. categorized supplier development into supplier incentives, competitive pressure, and supplier assistance<sup>[14]</sup>. Based on the characteristics of different supplier development behaviors, supplier relationship development behaviors can be distinguished as direct and indirect supplier development. Direct supplier development reflects the buyer's active involvement in influencing the supplier's capabilities and performance, including the investment of knowledge-based resources such as human resources and technical commitment, as well as tangible resources such as directly providing production facilities, capital, space, and green raw materials or components. Indirect supplier development reflects the buyer firm's attempt to motivate the supplier to improve its performance independently. Examples include rewarding suppliers based on their fulfillment of requirements, applying competitive pressure through multi-sourcing that threatens elimination, and conducting continuous evaluation of the supplier's behaviors and outcomes.

Based on the actual circumstances, the buying firm can select the forms of supplier development. Different supplier development behaviors may exhibit synergistic effects. For example, after investing resources in a supplier, the buyer can promote the transformation of those resources through continuous evaluation and, based on the evaluation results, provide corresponding rewards to the supplier or apply certain competitive pressure<sup>[13]</sup>. Different relationship types between buyer and supplier also correspond to different supplier development approaches. For instance, under deeply embedded collaborative relationships guided by the buyer, specific asset investments can be used to further enhance the supplier's capabilities and deepen the bilateral relationship. In transactional business relationships, the buyer can combine evaluation with incentives, providing the supplier with stable, large-volume orders. This motivates the supplier to proactively meet the buyer's needs, achieving the effect of supplier development at a relatively lower cost.

## 3.3 Supplier Relationship Maintenance

To ensure that the bilateral relationship progresses in the intended direction, it is crucial to accurately identify the relationship's developmental path and correct any deviations promptly after supplier relationship development is initiated and throughout its process. Supplier monitoring plays a key role in this stage. Through performance evaluation and supervision, the enterprise can identify issues with suppliers and collaborate with them to formulate improvement plans, thereby ensuring that supplier behaviors and outcomes continuously meet the enterprise's established requirements. The following are the

supplier monitoring strategies; the monitoring mechanisms typically include:

### 3.3.1 Performance Evaluation and Supervision

- (1) Periodic Evaluation: Conduct regular performance evaluations of suppliers to ensure they meet requirements and pursue continuous improvement.
- (2) Quality Control: Monitor suppliers' quality control processes through methods such as sampling inspections and audits.
- (3) Communication Mechanism: Establish effective communication channels to promptly resolve issues that arise during cooperation.
- (4) Contract Management: Use contract terms to regulate supplier behavior and safeguard the interests of both parties.
- (5) Ongoing Monitoring: Supplier evaluation is not a one-time activity but an ongoing process. The enterprise needs to regularly monitor supplier performance to ensure they consistently meet established standards. This may involve regular performance reviews and feedback meetings, as well as corrective measures when necessary.

### 3.3.2 Consolidate and optimize supplier relationships

- (1) Supplier Optimization: Select and optimize suppliers based on evaluation results; choose excellent suppliers and eliminate unqualified ones.
- (2) Risk Management: Identify potential risks through monitoring mechanisms and formulate corresponding response strategies.
- (3) Cooperation and Collaboration: Establish closer cooperative relationships with suppliers, share information, engage in collaborative planning, and promote mutual benefit for both parties.
- (4) Technological Innovation: Encourage suppliers to adopt new technologies to enhance production efficiency and product quality, and to reduce supply prices.

## 4. Conclusion

This paper proposes a series of strategies covering supplier selection and management, performance evaluation and supervision, supplier relationship management, and risk management. By implementing these strategies, enterprises can better respond to market changes, reduce operational risks, and enhance their competitiveness. Meanwhile, supplier relationship management is a systematic and dynamic process that requires enterprises to continuously adjust and optimize their approaches. As technology advances and market conditions evolve, new challenges and opportunities will continue to emerge. Therefore, enterprises must maintain flexibility and adaptability, consistently carry out supplier evaluation and monitoring, and emphasize the important role of the core stage—supplier relationship development. They should also actively implement multiple synergistic supplier development behaviors based on their internal and external characteristics and adjust management strategies in a timely manner to cope with the ever-changing external environment. By refining the management of supplier relationships, enterprises can ensure the stability and efficiency of their supply chains, thereby securing a favorable position in the highly competitive market.

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## Conflict of Interests

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# Digital Inclusive Finance Empowers the High-Quality Development of County Economies in Shaanxi Province

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**Abstract:** With the vigorous implementation of the national rural revitalization strategy, digital inclusive finance has been practiced in the fields of “agriculture, rural areas, and farmers”. It has effectively addressed the issue of financial service exclusion in rural areas, improved the efficiency of financial services in rural regions, and injected vitality into the economic and social development of county areas. As an underdeveloped western province, Shaanxi faces a relative shortage of financial resources, which to a certain extent restricts the development of its county economies. This paper first describes the basic overview of Shaanxi’s county economies, then clarifies the impact mechanism of developing digital inclusive finance on the high-quality development of county economies, and finally analyzes the current development dilemmas of digital inclusive finance in Shaanxi’s counties. Corresponding implementation pathways are proposed to enable digital inclusive finance to better empower the high-quality development of Shaanxi’s county economies in the future.

**Keywords:** Digital Inclusive Finance; County Economy; High-Quality Development

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## 1.Introduction

Since China implemented the rural revitalization strategy, it has built a new development pattern based on new development concepts and promoted high-quality economic development. The Report to the 20th National Congress of the Communist Party of China points out that high-quality development is the primary task for building a modern socialist country in an all-round way. High-quality development has strong policy orientation, and its multi-dimensional attributes have been widely recognized. How to promote high-quality development has become a major practical issue facing China<sup>[1]</sup>. Digital inclusive finance is a new financial format that integrates digital technology with financial services under the new technological background<sup>[2]</sup>. The combination of the two is a strong driving force for financial work in the new journey and an important way to promote high-quality development. China’s e-commerce, digital communication technology, Internet, artificial intelligence and other industries have developed well. The integration of the digital economy in multiple fields has laid a foundation for the development of digital inclusive finance and nurtured new momentum for high-quality economic development. Under the current situation of tight resource constraints, declining demographic dividends, and expanding structural transformation needs, digital inclusive finance has injected more convenient, accessible, and active financial tools into economic development. It is imperative to vigorously develop digital inclusive finance to promote high-quality economic development.

At present, the global economic digital transformation is accelerating. Emerging technologies such as information technology, data analysis, and artificial intelligence are reshaping the economic pattern. As a new financial service model, digital inclusive finance is rapidly changing the operation mode of the traditional financial system and exerting a profound impact on economic development. Theoretically, through technological means, digital inclusive finance can provide more convenient, efficient, and inclusive financial services, expand financial service channels, reduce financial service costs, and enable more county enterprises and residents to enjoy high-quality financial services, making it an important engine for promoting the high-quality development of county economies. However, the existence of the “digital divide” puts county enterprises and residents at a significant disadvantage in accessing and applying digital technologies. Against this background, whether digital inclusive finance can effectively promote the high-quality development of county economies is a question worthy of in-depth discussion. If yes, how does digital inclusive finance promote the high-quality development of county economies? Will its role be affected by the level of traditional financial development? These are extremely important and urgent issues to consider at present.

## **2. Basic Overview and Existing Problems of Shaanxi’s County Economies**

According to official statistics, 80% of Shaanxi’s land area is in county regions, 55% of its permanent population lives in counties, and nearly half of its economic output comes from county economies. Promoting the high-quality development of county economies has become the key to realizing common prosperity for all people in Shaanxi, building a new urbanization system, tapping new economic growth points, and stabilizing and expanding domestic demand. In recent years, with Shaanxi’s increased investment of funds and policy inclination towards counties, the development level of Shaanxi’s county economies has steadily improved, but structural contradictions still exist, restricting the quality and efficiency improvement of Shaanxi’s county economies<sup>[3]</sup>.

### **2.1 Continuous Expansion of County Economic Scale but Weak Overall Strength**

In 2024, the GDP of county areas in the province reached 1.6 trillion yuan, accounting for 47.3% of the province’s total, showing a continuous growth in the total volume of county economies. According to the “2024 Research on the High-Quality Development of China’s County Economies” released by CCID Consulting under the Ministry of Industry and Information Technology, Shenmu City of Shaanxi Province ranked 28th among the top 100 counties in China with a GDP of 234.71 billion yuan. As an important part of the national Northern Shaanxi Energy and Chemical Industry Base, Fugu County was selected as one of the top 100 counties in western China with a GDP exceeding 100 billion yuan. Jingbian, Hancheng, Dingbian, and Binzhou also made the list of top 100 counties in western China. In addition, 21 counties have achieved a GDP exceeding 20 billion yuan.

Overall, Shaanxi’s county economies maintain a good development momentum, but there is still much room for improvement compared with the eastern coastal areas of China. In terms of total volume, Shaanxi’s county economies are generally weak, with low development levels, small economic scales, and few strong counties. There are 56 counties (cities) with a GDP of less than 20 billion yuan, and 40% of the counties (cities) have an economic growth rate lower than the provincial average, which has become a bottleneck restricting the high-quality development of the province’s economy. In terms of structure, Shaanxi’s county economies also show an unbalanced regional development pattern, with relatively backward development in Southern and Northern Shaanxi and significant regional development differences. Counties (cities) with a GDP of more than 20 billion yuan are mainly concentrated in Guanzhong and Northern Shaanxi, accounting for 88% of the total, showing a serious polarization between strong and weak counties. As “star” counties in Shaanxi, the proportion of per capita disposable income to per capita GDP in Shenmu and Fugu is lower than that of top 100 counties in developed provinces, indicating that Shaanxi needs to take more effective steps on the path of unifying “strong counties” and “prosperous people” to promote county economies to break through development bottlenecks.

### **2.2 Optimization and Upgrading of County Industrial Structure but Low Development Level**

In 2024, the tertiary industry structure of Shaanxi’s counties was 13.2:55.0:31.8. At present, Shaanxi has achieved the goal of eliminating “empty villages” in collective economies. Its apple, kiwifruit, and dairy goat industries rank first in the country, and the output value of protected agriculture has exceeded 100 billion yuan. Northern Shaanxi has formed a potential

industrial belt focusing on goats, red dates, and minor cereals; Guanzhong has formed a leading industrial belt focusing on dairy animals, beef cattle, vegetables, and grain; Southern Shaanxi has formed a characteristic industrial belt focusing on live pigs and tea. The industrial scale has been continuously expanded, industrial characteristics have become more prominent, and the quality of agricultural products has been continuously improved<sup>[4]</sup>. Despite these achievements, there are still problems of low development level in the industrial development of Shaanxi's counties. Some counties have an incorrect understanding of leading industries and blindly pursue "largeness, novelty, and comprehensiveness". Some leading industries have short chains, small output value scales, and low technological content of industrial products. Individual counties rely on traditional development paths, taking energy and chemical industry or cultural tourism as their leading industries, but fail to fully explore and utilize their resource advantages, resulting in the prominent contradiction of relatively primitive industries. In addition, there is a high degree of similarity in development among counties, with widespread phenomena such as industrial homogenization, unbalanced production capacity, insufficient coordination, and low concentration of industrial clusters.

### **2.3 Orderly Progress of Urbanization Construction but Inadequate Integration**

To promote the integrated development of urban and rural areas and the integration of the primary, secondary, and tertiary industries, counties (cities) in Shaanxi have accelerated the pace of urban construction in recent years. In 2024, the urban population of Shaanxi's counties reached 26.15 million, with an urbanization rate of 66.14%, and the number of county legal entities exceeded 250,000. In 2023, the non-public ownership economy in the province's counties accounted for 46% of the total GDP of the province's counties, further enhancing the endogenous driving force for the development of county economies. With the orderly progress of urbanization construction, residents' lives have been continuously improved. In 2024, the growth rate of per capita disposable income of rural residents in the province was 2.4 percentage points higher than that of urban residents, and the urban-rural income ratio narrowed to 2.57:1. In addition, the total retail sales of consumer goods in the province's counties reached 401.824 billion yuan, with a growth rate 2.4 percentage points higher than that of the province's total retail sales of consumer goods.

The orderly progress of urbanization construction has, to a certain extent, realized the mutual promotion and complementary advantages between urban and rural areas, but there are still some problems. In 2022, county market entities accounted for only 28.92% of the province's total market entities, which is still low relative to the status and role of county economies. In recent years, through the strong village plan and thinning action for rural collective economies, the township collective economies in Shaanxi have gradually expanded, but as of 2023, the proportion of "weak villages" with an operating income of less than 50,000 yuan still reached 25.5%.

The above data shows that the driving effect of cities on rural areas in urbanization construction is insufficient, and the integration of urban and rural areas is not deep enough. Firstly, restricted by factors such as agricultural infrastructure investment and the development level of agricultural socialized services, the overall level of agricultural modernization in Shaanxi is still low, making it difficult for urbanization construction to promote the integrated development of agriculture with industry and service industries<sup>[5]</sup>. Secondly, the underdeveloped county financial market leads to insufficient guarantee of development factors, prominent problems of financing difficulties and high financing costs, and insufficient vitality of social capital. Enterprises mainly rely on bank loans for financing, but problems such as difficulty in obtaining loans and short loan terms are common. Finally, the development of industrial parks lacks overall planning, and some supporting facilities are only limited to road access, electricity supply, and water supply, with insufficient supporting facilities in financial insurance, enterprise incubation, talent training, etc. Investment promotion focuses on introduction rather than cultivation, resulting in the problem of "attracting but not retaining" enterprises. In summary, although Shaanxi has made achievements in urbanization construction, it still needs to further improve the comprehensive carrying capacity of counties to achieve the goal of high-quality urban-rural integration<sup>[6]</sup>.

## **3. Analysis of the Impact Mechanism of Digital Inclusive Finance on the High-Quality Development of County Economies**

### 3.1 Direct Impact Mechanism

Relying on big data credit investigation and mobile terminal access, digital inclusive finance breaks through the dependence of traditional finance on physical outlets and collateral assets, and incorporates a large number of farmers, individual industrial and commercial households, and start-up enterprises in counties that were previously excluded from the formal credit system into the scope of services. As a result, the credit supply curve shifts overall to the right, and the capital accessibility of micro-subjects in counties is significantly improved in the short term. When financing constraints are relaxed, enterprises can timely update production equipment, expand production capacity, and absorb local labor; agricultural operators can also obtain the necessary funds for purchasing improved seeds, agricultural machinery, and expanding reproduction, thereby directly increasing the total level of county economies and improving resource allocation efficiency<sup>[7]</sup>. The capital deepening effect brought about by credit expansion enables marginal “jump-style” improvements in per capita GDP and total factor productivity, providing the primary driving force for the high-quality development of county economies.

### 3.2 Indirect Impact Mechanism

On the basis of directly injecting funds, digital inclusive finance indirectly stimulates the endogenous growth momentum of counties through three progressive channels. Firstly, the key to unblocking the technological innovation channel lies in the risk control model of “data replacing collateral”. Digital platforms use transaction flows, social behaviors, and logistics information to build multi-dimensional credit profiles, which significantly reduces the financing threshold for technology-based small and micro enterprises in the R&D stage and alleviates the inherent “financing gap” problem in innovative activities<sup>[8]</sup>. The increase in R&D investment is directly reflected in the growth of the number of patent authorizations and the output value of new products, thereby improving the total factor productivity of counties and realizing the quality transformation of economic development<sup>[9]</sup>.

Secondly, the simultaneous improvement of technological innovation and capital accessibility creates necessary conditions for the industrial upgrading channel. After obtaining continuous medium and long-term loans, county leading industries—such as intensive processing of agricultural products and characteristic manufacturing—can introduce intelligent production lines and green process equipment to move up the value chain. At the same time, supporting service industries such as cold chain warehousing, e-commerce live broadcasting, and data annotation have rapidly emerged, promoting the transformation of the industrial structure from “dominance of the primary industry” to “integration of the three industries” and completing the efficiency transformation.

Finally, industrial expansion and increased employment activate the consumption expansion channel through the income effect. The sinking of digital credit and mobile payment enables rural residents to smooth intertemporal consumption and release upgraded demands such as education, medical care, and durable goods. The expansion of consumption scale, in turn, stimulates local enterprises to expand supply, forming a mutually promoting cycle of “production-consumption” and providing sustainable demand-side support for the high-quality development of county economies.

## 4.Path Suggestions for Digital Inclusive Finance to Empower the High-Quality Development of Shaanxi’s County Economies

According to the Digital Inclusive Finance Index released by Peking University, the development level of digital inclusive finance in Shaanxi’s counties has steadily improved year by year, with initial results. However, there is still a significant gap compared with eastern provinces, and the development is unbalanced among regions. The insufficient development of digital inclusive finance is mainly due to the following four reasons.

Firstly, county financial institutions have limited product innovation capabilities and business approval authority. In addition, the main audience of digital inclusive finance is small in scale and scattered in distribution, making it difficult for county financial institutions in Shaanxi to control risks of products and high service costs, resulting in insufficient effective supply.

Secondly, digital inclusive finance has significantly expanded the service scope of traditional finance. As a new product of the development of the financial system, it inevitably faces a certain degree of regulatory lag. The imperfect regulatory system makes its development accompanied by potential risks.

Thirdly, the credit information of farmers and the vast majority of small and micro enterprises in Shaanxi is lacking. When

financial institutions provide services and products to them, information asymmetry caused by the imperfect credit reporting system leads to financial repression.

Finally, digital inclusive finance mainly provides services to the poor, farmers, and small and micro enterprises. Most of these groups are not familiar with the digital inclusive finance model, and their lack of financial knowledge results in low acceptance of digital inclusive finance.

To promote digital inclusive finance to better assist the high-quality development of Shaanxi's county economies and serve rural revitalization, efforts can be made in the following four aspects:

#### **4.1 Improve the Supply Level of Digital Inclusive Finance**

The root cause of county financial institutions' "willingness to lend but dare not lend" lies in the upward shift of both product templates and approval authority, resulting in a lack of "suitable tools" to meet the scattered and small-sum financing needs of the agricultural industrial chain. The provincial government should take the lead in establishing three scenario-based laboratories: "Qinling-Bashan Mountains, Guanzhong Plain, and Northern Shaanxi Loess Plateau". Common modules such as satellite remote sensing, warehouse receipt Internet of Things, and carbon sink measurement should be developed into "plug-and-play" components and delegated to county branches. At the same time, county legal persons should be granted independent approval authority for credit loans below 1 million yuan, and asset-backed loans within 5 million yuan should be processed online through "machine scoring + remote face-to-face signing", reducing the approval time from 15 working days to 3 days<sup>[10]</sup>. For the first loans issued using the above modules, the provincial finance should provide a risk subsidy of 1% of the loan balance and conduct bulk guarantees with the National Financing Guarantee Fund through the "top-to-top" model, driving the average annual growth rate of county digital inclusive loans to no less than 25%, and truly transforming the "supply shortcoming" into a "growth springboard".

#### **4.2 Improve Digital Inclusive Finance Supervision Measures**

The prominent contradiction facing county digital inclusive finance supervision is "chaos when loosened, and stagnation when tightened". Shaanxi should launch the "County Regulatory Sandbox Online Platform" within the framework of the Xi'an National Inclusive Finance Reform Pilot Zone, initially opening 5 types of innovative businesses such as "farmland management right + satellite remote sensing" mortgage loans and "live livestock + intelligent ear tag" pledge loans, with a 12-month safety test period. The platform will real-time capture 4 indicators: loan non-performing rate, complaint rate, leverage ratio, and abnormal capital flow rate. Triggering the red line will automatically suspend the filing of new businesses<sup>[11]</sup>. At the same time, a "white list" compensation mechanism should be established to provide a 5% financial interest subsidy for non-performing loans generated during the sandbox period, improving the risk tolerance of grass-roots institutions for agricultural and small micro-loans, and realizing "stable innovation and controllable risks".

#### **4.3 Establish a Digital Inclusive Finance Credit Reporting System**

"Lack of information is more terrible than lack of collateral". The provincial government should integrate 42 types of data including public security household registration, agricultural and rural confirmation rights, taxation, e-commerce transactions, and water, electricity, and gas payment to build a provincial-level "Qinxin Tong" county credit information platform. Each farmer household and small and micro enterprise will be assigned a unique 15-digit digital credit code and a credit score ranging from 350 to 850<sup>[12]</sup>. For entities that reach grade B or above for the first time, the provincial finance will issue 30BP interest rate vouchers (loan interest subsidies), and the municipal finance will provide 50% guarantee fee subsidies, forming a positive incentive of "good credit-real benefits". At the same time, the "Regulations on County Credit Information in Shaanxi Province" should be issued to clarify the calling rules of "one-time authorization, three-year validity, and on-demand retrieval". It is striving to achieve a credit filing coverage rate of more than 90% within three years, basically eliminating financial repression caused by information asymmetry<sup>[13]</sup>.

#### **4.4 Popularize Digital Inclusive Finance Knowledge Education**

"Unable to use and dare not use" is still the biggest obstacle for rural groups to access digital credit. Counties should install 55-inch interactive screens in 17,000 agricultural information service centers, and launch 30 episodes of scenario dramas in Northern Shaanxi dialect, Guanzhong dialect, and Southern Shaanxi Hakka dialect, explaining "mobile phone withdrawal,



online loan renewal, and anti-fraud formulas” through Qinqiang micro-operas. Two regular “financial night school” live broadcasts should be held every month. For farmers who complete 20 minutes of study and pass a 10-question test, operators will immediately give 2GB data packages, and insurance companies will give 20,000 yuan of accidental injury insurance, forming a “learning-testing-reward” closed loop. A unified “Digital Inclusive Finance Promotion Week” should be held after the autumn harvest, providing 50,000 yuan of provincial promotion funds for excellent cases. It is striving to increase the proportion of active digital inclusive finance users in counties by 20 percentage points within one year, making “willing to use, able to use, and dare to use” a new normal.

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# Research on the Impact of Environmental Protection Tax on the Efficiency of Urban Green Development ——A Quasi-Natural Experiment Implemented Based on the Environmental Protection Tax Law

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**Abstract:** This study employs a quasi-natural experiment framework based on the policy shock of the 2018 Environmental Protection Tax Law implementation. Utilising panel data from 280 prefecture-level cities in China spanning 2010–2022, it comprehensively applies methods including the Difference-in-Differences (DID) approach and spatial econometric models to examine the policy effects of environmental protection tax on urban green development efficiency. Empirical findings indicate that the environmental protection tax significantly enhances urban green development efficiency, with this conclusion remaining robust after parallel trend tests and other stability checks. Mechanism analysis reveals that industrial structure upgrading serves as a key mediating pathway, while public environmental awareness exerts a positive moderating effect on policy outcomes. Spatial econometric results confirm that the environmental protection tax positively influences green development efficiency both locally and in neighbouring cities. The study offers insights for refining environmental taxation policies and promoting regional green coordination: synergies between industrial structure and public participation should be strengthened; differentiated policies should be implemented according to varying urban foundations; and regional linkage strategies should be formulated while accounting for spatial spillover effects.

**Keywords:** Environmental Protection Tax; The Efficiency of Urban Green Development; Difference-In-Differences; Spatial Metrology

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## 1.Introduction

For a long time, China's extensive economic growth model relied heavily on substantial resource inputs and energy consumption. The expansion of high-pollution, energy-intensive industries led to the persistent deterioration of the ecological environment, with frequent smog episodes and water pollution emerging as prominent obstacles to sustainable economic development. Green development represents a significant theoretical innovation and practical achievement forged by China in addressing ecological and environmental challenges<sup>[1]</sup>. Its essence lies in reconciling economic growth with environmental protection by establishing a new development paradigm where the economy, environment, and society coexist in synergy. This approach achieves the organic unity of economic expansion, ecological restoration, and social stability. Consequently,

China has established the concept of green development as the core guiding principle for socio-economic advancement in the new era. It has defined the ‘coordinated promotion of carbon reduction, pollution control, ecological expansion, and economic growth’ as its developmental strategy for this era, explicitly advocating for ‘advancing ecological priority, resource conservation, intensive use, and green, low-carbon development.’ This underscores the pivotal role of green development within the broader framework of modernisation. Enhancing the efficiency of green development represents the core pathway to resolving the tension between environmental protection and economic growth, thereby achieving high-quality development.

Taxation, as an economic instrument of state macro-regulation, plays a vital role in advancing environmental protection and achieving green development. To effectively address environmental challenges, China enacted the Environmental Protection Tax Law in 2016, which formally came into effect in 2018. As a milestone in China's journey towards environmental governance through the rule of law, this green tax legislation employs fiscal leverage to internalise environmental costs. Through a differentiated taxation mechanism – levying higher taxes on greater pollution and lower taxes on reduced pollution – it compels enterprises to innovate production methods and reduce emissions. Amidst the accelerated pursuit of the dual carbon goals, delving into the Environmental Protection Tax Law's impact mechanisms on urban green development efficiency and analysing its implementation outcomes across cities with varying regional and economic foundations not only advances the theoretical framework of environmental policy research but also provides crucial practical guidance for refining environmental governance strategies and fostering coordinated economic and ecological development.

## 2.Literature Review

Academic research has yielded substantial findings regarding the policy effects of environmental protection taxation. At the micro-enterprise level, studies indicate that the implementation of the Environmental Protection Tax Law has significantly increased environmental governance investments by heavily polluting enterprises<sup>[2]</sup>, stimulated corporate motivation for green technological innovation<sup>[3]</sup>, and propelled the green transformation of heavily polluting enterprises<sup>[4]</sup>. Additionally, scholars have observed that the implementation of the Environmental Protection Tax Law not only facilitates the attraction of green investors to enterprise<sup>[5]</sup>, but also enhances both the quality and quantity of green technological innovation within firms<sup>[6-8]</sup>, thereby exerting a positive influence on their total factor productivity<sup>[9-10]</sup>. However, alternative perspectives have been put forward, suggesting that environmental tax policies may to some extent inhibit innovation activities<sup>[11]</sup> and induce opportunistic behaviours such as ‘greenwashing’ among enterprises<sup>[12]</sup>. At the regional level, Wang W. et al.<sup>[13]</sup>(2024) conducted empirical tests using prefecture-level city data, finding that the implementation of the Environmental Protection Tax Law effectively improves urban air quality. Zhou B. et al.<sup>[14]</sup>(2022) further emphasised that environmental protection tax policies significantly enhance urban atmospheric environmental quality, with long-term policy effects outperforming short-term ones. Additionally, scholars have identified positive impacts of environmental protection tax policies on boosting regional green total factor productivity<sup>[15]</sup>, accelerating regional green transformation<sup>[16]</sup>, and promoting air pollution control alongside regional high-quality development<sup>[17]</sup>.

Following the introduction of the green development concept, academia has conducted research across multiple dimensions, including its connotations, measurement, and influencing factors. Regarding conceptual content, some scholars have preliminarily elaborated on its definition, strategic value, and development mechanisms<sup>[18-20]</sup>. Loiseau E.<sup>[21]</sup>(2016) further emphasised that green development constitutes an economic growth paradigm centred on efficiency optimisation, systemic harmony, and ecological sustainability, with its core objective being the establishment of synergistic relationships between economic, ecological, and social systems. Regarding measurement methodologies, scholars predominantly employ Data Envelopment Analysis (DEA) and its extended models<sup>[22-23]</sup>. Yang Yuping et al.<sup>[24]</sup>(2022) employed the Super-SBM model to measure green development efficiency, though it excluded key input factors such as resource consumption; Lan Zirui<sup>[25]</sup>(2021) employed a total factor non-radial direction distance function and SBM-DEA model, comprehensively considering inputs, expected outputs, and non-expected outputs for measurement; Jing Jianzhuang et al.<sup>[26]</sup>(2024) further utilised the SBM-GML model and exploratory spatial data analysis model to calculate green development efficiency; Additionally, Fu J.<sup>[27]</sup>(2022) measured urban green development efficiency using a three-stage DEA model, though the sample was limited to

selected prefecture-level cities in Liaoning and Jiangsu provinces; Liu X.<sup>[28]</sup>(2023) combined super-efficiency SBM-DEA with ESDA modelling to assess and evaluate industrial green development efficiency. Regarding influencing factors, existing scholarly research has identified that digital finance<sup>[29]</sup>, urbanisation<sup>[30]</sup>, regional market integration<sup>[31]</sup>, and carbon trading mechanisms<sup>[32]</sup> promote regional economic structural transformation and upgrading. These factors optimise the allocation of regional factors of production, enhance regional economic efficiency, and thereby facilitate green development. Wang W. et al.<sup>[33]</sup>(2023) demonstrated that the ‘Made in China 2025’ pilot policy enhances urban green development efficiency through mechanisms such as technological advancement. Zhu B. et al.<sup>[34]</sup>(2019) found that industrial structure promotes green development efficiency, with structural optimisation exerting a greater impact than rationalisation. Yang X. et al.<sup>[35]</sup>(2022) developed a spatial Durbin model based on the STIRPAT framework, revealing that financial agglomeration exhibits a pronounced non-linear effect on neighbouring regions' green development efficiency. Li T. et al.<sup>[36]</sup>(2024) observed that the promotional effect of FDI quality on green development efficiency is moderated by environmental regulations, diminishing progressively as regulatory intensity increases.

In summary, existing scholarship has conducted extensive research on the policy effects of environmental protection taxes and green development efficiency. However, few studies have integrated these two concepts within a unified framework to explore the operational mechanisms and spatial effects of environmental taxes on urban green development efficiency. Consequently, the logical chain linking the Environmental Protection Tax Law to enhancing urban green development efficiency remains unconnected, leaving scope for further investigation. Consequently, this paper establishes benchmark, mediation, moderation, and spatial models after clarifying the operational mechanisms linking environmental protection tax law and green development efficiency. It comprehensively examines the direct impact, transmission pathways, and spatial characteristics of environmental protection tax policies on urban green development efficiency. The innovative value lies primarily in: 1) establishing an analytical framework linking the Environmental Protection Tax Law to urban green development efficiency, focusing on the coordinated development mechanism between economy and environment at the urban scale, thereby enriching the systematic analysis of how environmental protection taxes influence green development efficiency; 2) employing a Difference-in-Differences (DID) model and spatial econometric models to identify policy effects through a quasi-natural experiment while revealing the spatial spillover characteristics of green development efficiency, thus addressing the neglect of the spatial dimension in previous research.

### 3. Theoretical Analysis and Research Hypotheses

Given the public good attributes and negative externalities inherent in environmental pollution<sup>[16]</sup>, market mechanisms struggle to efficiently regulate environmental resource allocation, necessitating government intervention through regulatory measures such as environmental taxation. The implementation of the Environmental Protection Tax Law enhances urban green development efficiency through a dual mechanism: firstly, its ‘polluter pays’ principle – ‘more emissions, higher taxes; fewer emissions, lower taxes; no emissions, no tax’ – internalises the external costs of pollution, increasing the economic burden of emissions on enterprises. Firms continuing high-pollution production face higher tax liabilities. When the cost of emissions exceeds the threshold for technological upgrades, this forces energy-intensive enterprises to phase out outdated production capacity. As Pigouvian tax theory indicates, environmental taxation corrects market failures by compelling enterprises to incorporate environmental costs into production decisions, thereby shifting pollution control from ‘passive compliance’ to ‘proactive emission reduction’. Concurrently, differentiated tax rates and emission reduction incentives create positive reinforcement mechanisms. According to the Porter Hypothesis, well-designed environmental regulations stimulate corporate innovation through compensation effects. Savings from environmental taxes can be redirected towards green R&D investment, fostering a virtuous cycle of ‘emission reduction – cost reduction – innovation’. Simultaneously, the legal enforceability and implementation strength of the environmental protection tax significantly surpass those of the previous pollution discharge fee system. Its long-term, stable policy signals help establish predictable innovation expectations, driving the accumulation and diffusion of green technologies, thereby enhancing the overall green development efficiency of cities<sup>[37]</sup>. In summary, the Environmental Protection Tax Law drives corporate green transformation through dual mechanisms of constraint and incentive, optimises urban resource allocation and industrial structure, and synergistically enhances both

ecological environment quality and the greening of economic development, thereby influencing urban green development efficiency. Consequently, the following hypothesis is proposed:

H1: The implementation of the Environmental Protection Tax Law can enhance urban green development efficiency.

Based on Porter's hypothesis and the innovation compensation effect, the environmental protection tax primarily optimises industrial structure through three pathways: technology, consumption, and investment. On the technological front, by increasing pollution costs, the tax compels enterprises to boost investment in green technology R&D. This innovation-driven approach compensates for profit reductions caused by environmental regulations, thereby fostering green industry development and accelerating industrial upgrading. This process aligns with the reverse logic of the 'pollution refuge' hypothesis—environmental regulations no longer drive enterprises away but instead catalyse industrial advancement through technological innovation. At the consumption level, the implementation of environmental protection tax leads to price increases for polluting products. According to demand elasticity theory, consumer demand for such products declines, shifting towards green alternatives. This creates a reverse-pressure mechanism: 'greening of consumption structure – transformation of industrial supply.' At the investment level, the environmental tax elevates compliance costs for polluting industries, curbing expansion in high-energy-consuming sectors while incentivising capital flows towards low-carbon services and strategic emerging industries. This optimises industrial structure, as factor price changes guide capital towards high-efficiency sectors, accelerating industrial upgrading. Such structural advancement further reduces pollution intensity per unit output, achieving synergistic reductions in urban resource consumption and environmental pollution while enhancing green development efficiency. Moreover, the accumulation of green technologies and preference for clean factor inputs resulting from industrial upgrading will provide sustained momentum for urban green development, forming a virtuous cycle of 'policy regulation – industrial upgrading – green development'. In summary, the following hypothesis is proposed:

H2: The implementation of the Environmental Protection Tax Law enhances the efficiency of urban green development by promoting industrial upgrading.

Based on stakeholder theory and signalling theory, public environmental awareness functions as a 'policy effect amplifier' for environmental tax legislation through dual pathways: 'stakeholder collaborative oversight' and 'efficient transmission of market signals'. This positively regulates the environmental tax law's role in enhancing urban green development efficiency. Stakeholder theory posits that the public, as a significant external oversight entity, influences government policy implementation and corporate environmental conduct through their environmental demands. Elevated public environmental awareness prompts local governments to enforce environmental tax legislation more rigorously via public scrutiny and consumer choices, while simultaneously incentivising enterprises to proactively optimise production processes and increase green technology investments. This dual effect amplifies the environmental tax law's capacity to enhance green efficiency. Signalling theory further emphasises that public attention, functioning as a market signal, amplifies the policy effects of environmental protection tax legislation. This enables enterprises to perceive environmental regulatory trends more clearly, thereby accelerating the pace of green transformation. Indeed, existing research has found that environmental policy implementation yields more significant outcomes in regions with higher levels of public environmental participation<sup>[38]</sup>. In summary, we propose the following hypothesis:

Hypothesis 3: Public environmental concern exerts a positive moderating effect between environmental protection tax legislation and urban green development efficiency.

## 4. Research Design

### 4.1 Model Design

#### (1) Baseline regression model

This study employs the implementation of China's Environmental Protection Tax Law in 2018 as a quasi-natural experiment, utilising a Difference-in-Differences (DID) model to identify the policy effects of the environmental protection tax on urban green development efficiency. The model specification is as follows:

$$Green_{it} = \alpha_0 + \alpha_1 Policy_{it} + Controls_{it}'\alpha_2 + \gamma_i + \theta_t + \varepsilon_{it} \quad (1)$$

$$Policy_{it} = Treated_{it} * Time_{it} \quad (2)$$

In equation (1),  $i$  denotes the city, and  $t$  denotes the year.  $Green_{it}$  denotes the level of green development efficiency for city  $i$  in year  $t$ ;  $Policy_{it}$  denotes the policy dummy variable for the Environmental Protection Tax Law  $Treated_{it}$  and  $Time_{it}$  represents policy and time dummy variables respectively;  $\alpha_0$  denotes the constant term,  $\alpha_1$  denotes the coefficient indicating the impact of environmental protection tax on the efficiency of urban green development;  $Controls_{it}$  serves as the selected control variable,  $\gamma_i$  and  $\theta_t$  represents city and time fixed effects, respectively,  $\varepsilon_{it}$  denotes the random disturbance term.

#### (2) Mediation Effect Model

To test Hypothesis 2 and examine the mediating role of industrial structure between environmental protection tax and urban green development efficiency, this study constructs the following mediation effect model, drawing on Jiang Ting's<sup>[39]</sup> (2022) research:

$$Str_{it} = \beta_0 + \beta_1 Policy_{it} + Controls_{it}'\beta_2 + \gamma_i + \theta_t + \varepsilon_{it} \quad (3)$$

Among these,  $Str_{it}$  serves as the mediating variable for industrial structure level,  $\beta_1$  represents the coefficient of the core explanatory variable's effect on the mediating variable. The meanings of the remaining variables remain consistent with those described earlier.

#### (3) Moderation Effect Model

To test Hypothesis 3 and examine the moderating effect of public environmental concern on the relationship between environmental protection tax and urban green development efficiency, this study constructs a moderation model as follows:

$$Green_{it} = \delta_0 + \delta_1 Policy_{it} + \delta_2 Pec_{it} + \delta_3 Policy_{it} * Pec_{it} + X_{it}'\delta_4 + \gamma_i + \theta_t + \varepsilon_{it} \quad (4)$$

Among these,  $Pec_{it}$  represents the moderating variable public environmental concern,  $Policy_{it} * Pec_{it}$  denotes the interaction term between environmental protection tax and the moderating variable, while the meanings of the remaining variables remain consistent with the preceding discussion.

## 4.2 Variable Description

### 4.2.1 Dependent variable

Urban Green Development Efficiency (Green). Green development efficiency serves as a crucial indicator for measuring the coordination between regional economic growth and environmental protection, as well as sustainable development. It reflects the comprehensive and efficient utilization of resources and the ecological environment. Drawing upon Tone's<sup>[40]</sup> (2002) research, this paper employs the Super-SBM model incorporating non-desirable outputs to measure green development efficiency. The specific indicators selected are as follows:

#### (1) Investment

In terms of capital input estimation, following the methodology of Zhang J. et al.<sup>[41]</sup> (2004), fixed asset investment is estimated using the perpetual inventory method. Labor input is approximated by the number of employees at year-end. Regarding energy input measurement, drawing on the research of Shi D. et al.<sup>[42]</sup> (2020), energy input is characterized by urban energy consumption derived from nighttime light data.

#### (2) Expected Output

To measure expected output, this study employs actual regional gross domestic product (GDP) as the indicator. To ensure data comparability, GDP data for each city is deflated using the GDP index of the corresponding province, with 2000 as the base year, to eliminate the impact of price factors.

#### (3) Non-expected output

This study selected the following three types of industrial pollutants as indicators for measuring undesirable outputs: industrial sulfur dioxide emissions, industrial smoke (dust) emissions, and industrial wastewater discharges.

Table 1: Urban Green Development Efficiency Indicator System

Indicator Type	Primary indicator	Secondary Indicators
Investment	Capital	Fixed Capital Stock
	Labor	Number of employees at the end of the year
	Energy	Total Energy Consumption



Indicator Type	Primary indicator	Secondary Indicators
Expected Output	Economy	Real GDP
Non-expected output	Environment	Industrial wastewater discharge volume
		Industrial SO <sub>2</sub> emissions
		Industrial smoke and dust emissions

#### 4.2.2 Core explanatory variable

Environmental Protection Tax Law Pilot Policy. This study establishes policy variables based on the tax rate autonomy granted to local governments under the Environmental Protection Tax Law. According to legal provisions, provinces may independently decide whether to raise environmental protection tax rates based on environmental carrying capacity, current pollution discharge levels, and ecological development needs (with the state only setting upper and lower limits for tax rates). As of the study's analysis date, 12 provinces/regions/municipalities (including Sichuan, Hebei, and Shandong) implemented tax rate increases, while the remaining regions maintained their original pollution discharge fee standards (tax burden transfer). Consequently, prefecture-level cities within provinces that raised tax rates were designated as the treatment group (Treat=1), and regions with tax burden transfer served as the control group (Treat=0). Given the policy's formal implementation in 2018, Treated=1 was assigned for 2018 and subsequent years, while Treated=0 was assigned for prior years. An interaction term Policy (Treat×Treated) was constructed as the core explanatory variable to examine the net effect of policy implementation.

#### 4.2.3 Mechanism Variable

Mediating variable: Industrial structure (str), measured by the share of tertiary industry value-added in GDP; Moderating variable: Public environmental concern (pea), measured using the natural logarithm of the annual average search index for “environmental pollution” and “smog” on Baidu, following the methodology of Zheng S. et al.<sup>[43]</sup>(2013).

#### 4.2.4 Control variables

To control for potential confounding factors affecting inclusive green growth and ensure the accuracy and reliability of research findings, this study introduces the following control variables based on existing literature: (1) Science and Technology Investment (sci), represented by the ratio of urban science and technology expenditure to fiscal expenditure; (2) Government Self-Sufficiency Capacity (gco), measured by the fiscal revenue-expenditure ratio; (3) Environmental regulation intensity (ER), measured by the comprehensive utilization rate of industrial solid waste in cities; (4) Information technology level (PHONE), represented by the number of mobile phone users at year-end; (5) Financial development level (FIN), measured by the ratio of year-end deposits and loans of financial institutions to GDP.

### 4.3 Data Source

Based on data availability, this study ultimately constructed its research sample using panel data from 280 prefecture-level cities in China spanning 2010–2022. The data primarily originated from the China Urban Statistical Yearbook, statistical bulletins of Chinese cities, DMSP nighttime light data, the EPS database, and Baidu Search Index. For the few missing data points in the sample, linear interpolation was employed to fill gaps. Table 2 reports the descriptive statistics.

Table 2: Descriptive Statistics Results

Category	Variable	Meaning	Sample Size	Mean	Standard Deviation	Minimum	Maximum
Explanatory variable	Policy	Environmental Protection Tax Law Pilot Program	3640	0.165	0.371	0	1
dependent variable	Green	Green Development Efficiency	3640	0.275	0.222	0.053	1.318
Mediating variable	Str	Industrial Structure	3640	42.403	10.165	14.36	83.87
Control variable	Pec	Public Environmental Awareness	3640	3.654	1.035	0.001	7.151



Category	Variable	Meaning	Sample Size	Mean	Standard Deviation	Minimum	Maximum
Control variables	gco	Government self-sufficiency	3640	0.452	0.221	0.056	1.541
	fina	Level of Financial Development	3640	2.538	1.226	0.588	21.3
	sci	Investment in Science and Technology	3640	0.017	0.018	0.001	0.207
	er	Environmental Regulation Intensity	3640	78.56	23.28	0.24	160.7
	phone	Level of informatization	3640	477.8	513	29	4433

## 5. Empirical Results Analysis

### 5.1 Baseline regression results

Table 3: Benchmark Regression Results

Variable	igg					
	(1)	(2)	(3)	(4)	(5)	(6)
Policy	0.026*** (0.008)	0.028*** (0.008)	0.028*** (0.008)	0.028*** (0.008)	0.028*** (0.008)	0.024*** (0.009)
gco		-0.084*** (0.032)	-0.089*** (0.033)	-0.087*** (0.033)	-0.081** (0.033)	-0.081** (0.033)
sci			0.561** (0.241)	0.555** (0.241)	0.581** (0.244)	0.511** (0.241)
er				0.001 (0.000)	0.000 (0.000)	0.000 (0.000)
fina					0.004 (0.003)	0.004 (0.003)
phone						0.000** (0.000)
Constant	0.271*** (0.002)	0.308*** (0.015)	0.301*** (0.015)	0.286*** (0.018)	0.272*** (0.022)	0.243*** (0.025)
Fixed time effects	Y	Y	Y	Y	Y	Y
Individual fixed effects	Y	Y	Y	Y	Y	Y
N	3640	3640	3640	3640	3640	3640
R <sup>2</sup>	0.740	0.740	0.741	0.741	0.741	0.742

\*\*\* indicates  $p < 0.01$ , \*\* indicates  $p < 0.05$ , \* indicates  $p < 0.1$ ; standard errors are shown in parentheses; the same applies below.

This study employs the Difference-in-Differences (DID) method to empirically examine the policy effects of the Environmental Protection Tax Law on urban green development efficiency. As shown in Table 3, while controlling for both time and individual fixed effects, the estimated coefficient of the core explanatory variable—Environmental Protection

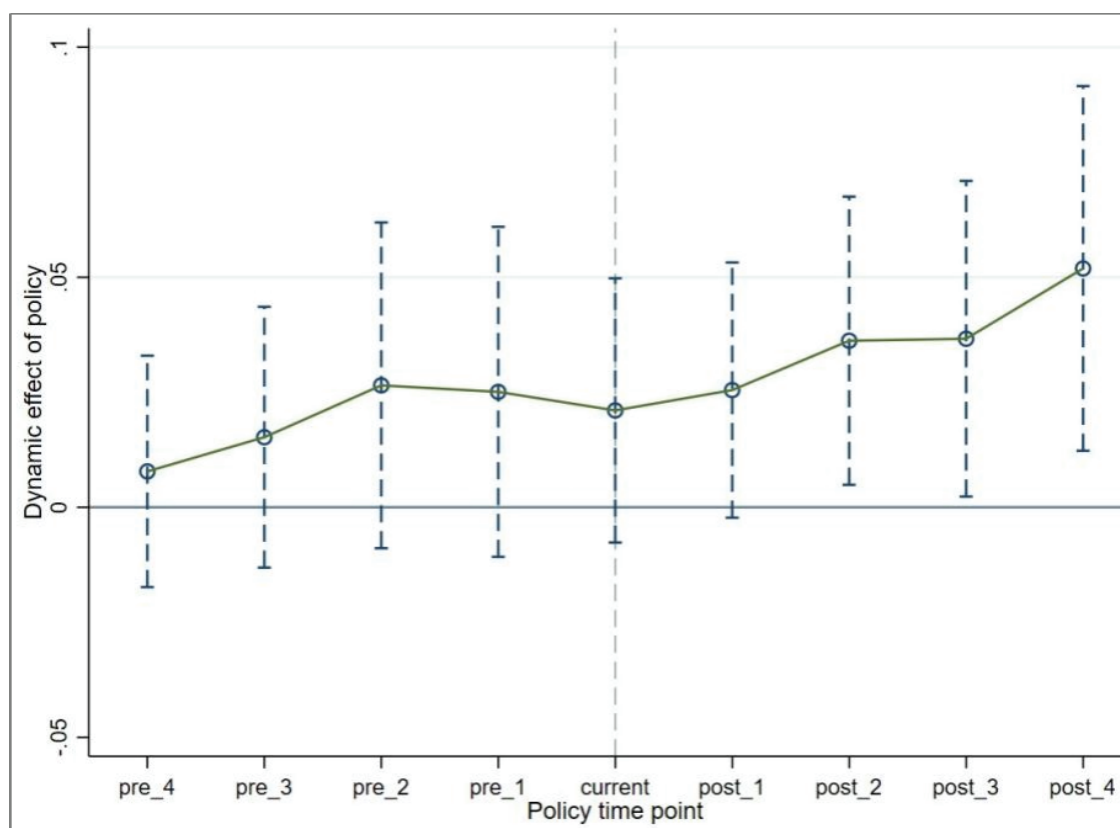
Tax (Policy)—remains positively significant regardless of whether control variables are included. This indicates that the policy implementation significantly enhances urban green development efficiency, and this result passes the robustness test of stepwise regression. The results in Column (6) of Table 3 show that after incorporating all control variables into the model, the regression coefficient for the pilot policy is 0.024 and remains significant at the 1% level. This indicates that the implementation of the environmental protection tax can effectively enhance urban green development efficiency. Hypothesis H1 is preliminarily validated.

## 5.2 Robustness Test

### 5.2.1 Parallel Trend Test

To ensure the validity of the results estimated by the difference-in-differences model, the parallel trends assumption must be satisfied, meaning that the green development efficiency of the experimental and control groups should exhibit consistent trends prior to policy implementation. To this end, this study adopts the event study method proposed by Jacobson et al.<sup>[44]</sup> (1993) to construct a parallel trends plot, as shown in Figure 1. The test results reveal that prior to policy implementation, estimated coefficients fluctuated randomly around zero and were statistically insignificant, indicating no systematic difference in green development efficiency between the experimental and control groups. Post-policy implementation, however, coefficients exhibited a significant positive jump that continued to widen. This dynamic effect validates the Environmental Protection Tax Law's role in promoting urban green development efficiency, satisfying the parallel trend assumption.

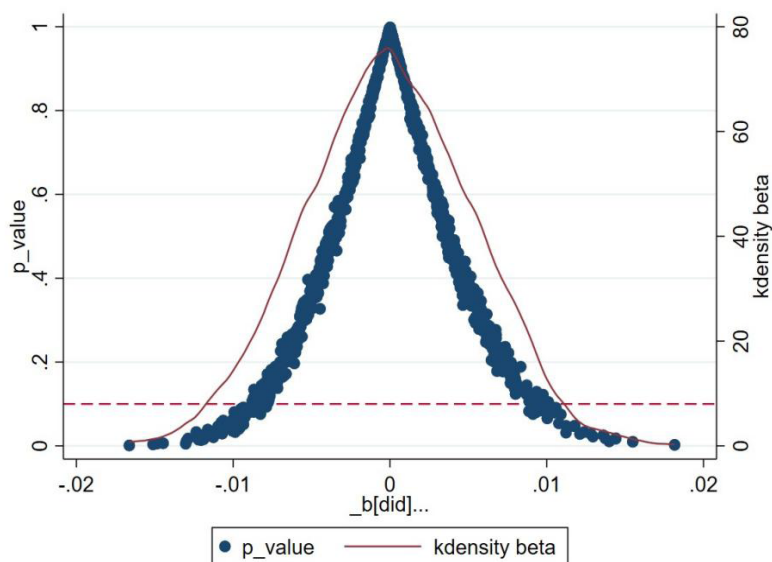
Figure 1: Parallel Trend Test



### 5.2.2 Placebo test

To further validate the reliability of the benchmark regression results, this study employs a placebo test method to eliminate the influence of other potential confounding factors. Specifically, by randomly generating the experimental group, 1000 simulated regressions were conducted on the sample. As shown in Figure 2, the estimated coefficients for the random treatment effect are densely clustered around zero, with the vast majority of regression results yielding P-values greater than 0.1. The coefficient for Policy in the benchmark regression (0.024) stands out as a clear outlier among the 1000 test results. These findings collectively indicate that the environmental protection tax's positive impact on urban green development efficiency remains unaffected by random factors, further validating the robustness of the estimation results.

Figure 2: Placebo Test



### 5.2.3 Endogeneity Test

To mitigate potential endogeneity issues in the model, this study further employs the instrumental variables approach for estimation. An effective instrumental variable must satisfy both the correlation condition and the exogeneity condition. Therefore, river density (river) is selected as the instrumental variable. Regarding correlation, stringent central government oversight of rivers means that regions with high river density face greater pollution control pressures. Local governments in these areas tend to enforce the Environmental Protection Tax Law more rigorously and are more likely to pilot environmental regulatory policies there, thus satisfying the correlation condition<sup>[45]</sup>. Regarding exogeneity, river density is a natural geographic feature that cannot directly influence urban green development efficiency, thus satisfying the exogeneity requirement for instrumental variables. The regression results for the instrumental variable are presented in Table 4. In the first-stage regression, the estimated coefficient for the instrumental variable River was 5.461, passing the 1% significance test, indicating that the instrumental variable satisfies the correlation condition. In the second-stage regression, the estimated coefficient for Policy remains significantly positive at the 1% level and passes the unidentifiability test and weak instrumental variable test. This indicates that after controlling for potential endogeneity bias, the implementation of the Environmental Protection Tax Law still significantly promotes urban green development efficiency.

Table 4: Endogeneity Test: Two-Stage Least Squares Method

Variable	2SLS estimation	
	Phase One(Policy)	Phase Two(Green)
	(1)	(2)
River	5.461*** (0.157)	
Policy		0.067*** (0.013)
Constant	-0.753*** (0.154)	0.829*** (0.135)
Control variables	Y	Y
Fixed time effects	Y	Y
Individual fixed effects	Y	Y
N	3360	3360
R <sup>2</sup>	0.879	0.746
Kleibergen-Paap rk LM		1080.87 [0.000]
Kleibergen-Paap Wald rk F		1202.33 {16.38}

The values within [] represent p-values, while those within {} denote the critical values at the 10% significance level for the Kleibergen-Paap Wald rk F weak identification test.

#### 5.2.4 PSM-DID Test

To address potential selection bias arising from dividing the experimental and control groups solely based on tax adjustment criteria, this study further employs Propensity Score Matching with Difference-in-Differences (PSM-DID) for validation. Using control variables as matching characteristics and leveraging kernel matching methods, the experimental and control groups are matched. Finally, the PSM-DID approach is applied to estimate the impact of the pilot policy on urban green development efficiency. The results are presented in Table 5, Column (1). The coefficient for Policy is 0.025, which is close to the DID regression result and remains significantly positive, confirming the robustness of the earlier estimation results.

#### 5.2.5 Eliminate other policy interference

During the sample period from 2010 to 2022, other environmental regulatory policy factors existed, such as the “Broadband China” pilot program and low-carbon city pilot initiatives. To exclude the influence of these policies on regression results and explore the net effect of the environmental protection tax law pilot policy, this study incorporates the low-carbon city pilot and “Broadband China” pilot programs into consideration. Policy dummy variables are constructed for each, and a multi-period DID regression is conducted. Results in Table 5, columns (2) and (3), show that the coefficients for the core explanatory variable Policy pass the 1% significance level test, validating the robustness of the benchmark regression results.

#### 5.2.6 Exclude municipalities directly under the central government

Given the unique characteristics of the four municipalities in terms of economic development levels, policy resource endowments, and administrative tiers, coupled with their direct relationship with the central government, they possess greater advantages in implementing and completing relevant policies. To avoid interference from their sample characteristics on the estimation results, this study conducted a regression analysis after excluding all municipal samples. The estimation results in Column (4) of Table 5 indicate that after excluding the municipality samples, the regression coefficient for the pilot policy on urban green development efficiency remains significantly positive at 0.025. This confirms the robustness of the baseline regression results.

Table 5: Robustness Test Results

Variable	PSM-DID	Eliminate other policy interference		Exclude municipalities directly under the central government
	(1)	(2)	(3)	(4)
Policy	0.025*** (0.008)	0.024*** (0.009)	0.024*** (0.009)	0.025*** (0.009)
kuandai		-0.003 (0.009)		
smartcity			0.004 (0.011)	
Constant	0.230*** (0.0279)	0.243*** (0.025)	0.242*** (0.025)	0.229*** (0.024)
N	3630	3640	3640	3588
Control variables	Y	Y	Y	Y
Fixed time effects	Y	Y	Y	Y
Individual fixed effects	Y	Y	Y	Y
R <sup>2</sup>	0.742	0.742	0.742	0.741

## 5.3 Heterogeneity Analysis

### 5.3.1 Environmental Regulation Heterogeneity

To examine the heterogeneous impact of environmental regulation foundations on policy effectiveness, this study categorizes the sample into two subgroups based on China's National Environmental Protection 11th Five-Year Plan classification standards: key environmental protection cities and non-key cities. The grouped regression results in Table 6 reveal significant heterogeneity in policy effects: the Policy coefficient is significant in the non-key environmental protection city sample but not in the key environmental protection city sample. This may stem from the fact that key environmental protection cities had already accumulated a high level of environmental regulation intensity prior to policy implementation. Following the implementation of the 11th Five-Year Plan, these cities established environmental monitoring networks and implemented measures such as total pollutant emission controls, resulting in relatively well-developed environmental governance systems. Consequently, the implementation of the Environmental Protection Tax Law functioned more as a supplement to existing policies, struggling to yield significant marginal improvements. In contrast, non-environmental protection key cities had relatively lax environmental regulations and weak policy foundations in the early stages. The implementation of the Environmental Protection Tax Law introduced entirely new constraints and incentive mechanisms, effectively stimulating enterprises' green technological innovation vitality, accelerating the transformation of production methods, and thereby enhancing green development efficiency.

Table 6: Test Results for Environmental Regulation Heterogeneity

Variable	Non-key environmental protection city	Key Environmental Protection Cities
	(1)	(2)
Policy	0.028** (0.012)	0.001 (0.014)
Constant	0.179*** (0.027)	0.286*** (0.052)
Control variables	Y	Y
Fixed time effects	Y	Y
Individual fixed effects	Y	Y
N	2,223	1,417
R <sup>2</sup>	0.655	0.795

### 5.3.2 Urban Hierarchical Heterogeneity

This study categorizes the sample cities into two types based on the city classification standards of China's 2022 Urban Commercial Appeal Ranking: economically developed regions (including first-tier, new first-tier, and second-tier cities) and economically underdeveloped regions (including third-, fourth-, and fifth-tier cities). The results of the grouped regression analysis in Table 7 indicate that in economically underdeveloped regions, the pilot policy significantly enhances green development efficiency. Conversely, in economically developed cities, the policy's impact fails to pass the significance test. This disparity likely stems from the fact that economically developed regions have already invested substantial resources in environmental governance, establishing relatively comprehensive environmental management systems and environmental protection technical standards. Under long-term policy constraints, enterprises in these regions have reached a relatively mature stage of green transformation. As an incremental policy, the environmental protection tax pilot program struggles to exert a significant marginal impact on green development efficiency. Conversely, in economically underdeveloped regions where environmental governance investments remain relatively insufficient and production methods are more extensive, the cost pressures imposed by the environmental protection tax can directly compel enterprises to alter their production models. By achieving cost reductions and efficiency gains through energy conservation and emission reduction, these regions experience a marked enhancement in green development efficiency.

Table 7: Test Results for Heterogeneity in Urban Hierarchy

Variable	economically developed cities	economically underdeveloped cities
	(1)	(2)
policy	0.017 (0.025)	0.020** (0.009)
Constant	0.595*** (0.134)	0.167*** (0.024)
Control variables	Y	Y
Fixed time effects	Y	Y
Individual fixed effects	Y	Y
N	637	3,003
R <sup>2</sup>	0.771	0.679

## 5.4 Analysis of Mechanism of Action

### 5.4.1 Mediation Analysis

Based on the preceding theoretical analysis, it is evident that the environmental protection tax may not directly enhance urban green development efficiency. Instead, it primarily promotes green development efficiency by facilitating industrial structure upgrading. To this end, this study employs Model 3 to test the mediating effect, with the results presented in Column (1) of Table 8. The regression coefficient for the environmental protection tax pilot policy on industrial structure upgrading is 1.279, which is statistically significant at the 1% level. These findings indicate that the pilot policy significantly promotes industrial structure upgrading, thereby exerting a positive effect on the measured green development efficiency. Based on the above analysis, Hypothesis 2 is supported.

Table 8: Mechanism Effect Test

Variable	Str	Green
	(1)	(4)
Policy	1.279*** (0.242)	0.019** (0.008)
Pec		0.010 (0.006)
Policy*Pec		0.033*** (0.009)
Constant	35.946*** (1.350)	0.216*** (0.028)
Control variables	Y	Y
Fixed time effects	Y	Y
Individual fixed effects	Y	Y
N	3640	3640
R <sup>2</sup>	0.901	0.744

### 5.4.2 Moderation Effect Analysis

To examine the moderating effect of public environmental concern on the policy effectiveness of the environmental protection tax pilot program, this study employs Model 4 for empirical analysis, with results presented in Column (2) of Table 8. Specifically, the regression coefficient for the environmental protection tax pilot program is 0.019, which is positively significant at the 5% level. The interaction term coefficient between public environmental concern and the environmental protection tax is 0.033, and it is positively significant at the 1% level. This indicates that public environmental concern can positively moderate the pilot policy's role in promoting the efficiency of green development. In summary, Hypothesis 3 is supported.



## 5.5 Spatial Metric Analysis

To further investigate the spatial spillover effects of pilot policies, this study constructs a spatial econometric model to test spatial effects. Spatial autocorrelation across the entire region reflects the degree of spatial interdependence in green development efficiency among cities. The global Moran's I index ranges from (-1, 1), where a positive index indicates positive spatial correlation in green development efficiency, a larger absolute value signifies deeper spatial association, and a value of 0 indicates no correlation between regions. Calculations based on the economic geographic distance nested matrix (Table 9) reveal that Moran's I indices measuring green development efficiency were significantly positive at the 1% significance level throughout the study period. This result confirms the existence of a significant positive spatial correlation in green development efficiency during the observation period, providing theoretical justification for subsequent in-depth analysis using spatial econometric models.

*Table 9: Moran's I Values for Urban Green Development Efficiency*

Time	Moran's I	Z	P
2010	0.085	3.081	0.001
2011	0.089	3.220	0.001
2012	0.117	4.220	0.000
2013	0.122	4.375	0.000
2014	0.116	4.210	0.000
2015	0.102	3.694	0.000
2016	0.072	2.597	0.005
2017	0.082	2.923	0.002
2018	0.102	3.609	0.000
2019	0.139	4.901	0.000
2020	0.110	3.866	0.000
2021	0.147	5.158	0.000
2022	0.120	4.221	0.000

Second, to determine an appropriate spatial econometric model, this study follows the methodology proposed by Elhorst<sup>[46]</sup> (2014) and employs a series of tests to assess the suitability of spatial models. Based on the results of the relevant tests presented in Table 10, this study selects the fixed-effects spatial Durbin model for empirical analysis. The regression results are shown in Table 11.

*Table 10: LM, Robust-LM, LR, Wald, and Huasman Test Results*

Testing Methods	statistical measure	p
LM-error	6.806	0.009
LM-lag	12.210	0.000
Robust-LM-error	62.553	0.000
Robust-LM-lag	67.957	0.000
LR-error	32.93	0.000
LR-lag	31.46	0.000
Wald-SEM	31.58	0.000
Wald-SLM	33.03	0.000
Huasman	67.93	0.000

Table 11: SDM Regression Results

Variable	SDM	Direct	Indirect	Total
	(1)	(2)	(3)	(4)
W×Policy	0.051*** (0.013)	0.029** (0.008)	0.064*** (0.014)	0.092*** (0.013)
$\rho$	0.147*** (0.034)			
Sigma2_e	0.013*** (0.000)			
Control variables	Y	Y	Y	Y
Fixed time effects	Y	Y	Y	Y
Individual fixed effects	Y	Y	Y	Y
N	3640	3640	3640	3640
R <sup>2</sup>	0.093	0.093	0.093	0.093

Column (1) of Table 11 shows that the coefficient of the spatial weighting term W×Policy is 0.051, significant at the 1% level. This indicates that the pilot policy exerts a positive influence on the green development efficiency of neighboring cities, demonstrating a positive spatial spillover effect. To comprehensively analyze the implementation effects of the pilot policy, the policy effects were further decomposed into direct effects, indirect effects (i.e., spatial effects), and total effects. The results are presented in columns (2) to (4) of Table 11. (4). The coefficient for the direct effect is 0.029, while that for the indirect effect is 0.064. This indicates that the pilot policy not only enhances green development efficiency in its own region but also positively impacts neighboring areas through spatial spillover effects.

## 6. Conclusions and Implications Recommendations

### 6.1 Conclusion

This study treats the implementation of China's Environmental Protection Tax Law in 2018 as a quasi-natural experiment, constructing a double difference model to systematically evaluate the policy's impact on urban green development efficiency and its underlying mechanisms. Empirical results indicate that the environmental protection tax policy significantly enhances urban green development efficiency. This conclusion remains robust after multiple tests, including placebo tests and PSM-DID analyses. Mechanism analysis reveals that industrial structure plays a crucial mediating role in the policy's impact on green development efficiency, while public environmental awareness exerts a positive moderating effect, significantly amplifying the policy's impact. Heterogeneity analysis indicates pronounced regional differences in the law's effects, with more pronounced impacts observed in non-environmental priority cities and economically underdeveloped cities. Spatial econometric analysis reveals significant spatial spillover effects in urban green development efficiency. The implementation of the Environmental Protection Tax Law not only substantially enhances green development efficiency within the region but also exerts positive radiating effects on surrounding cities.

### 6.2 Revelation suggestion

Based on the findings of this study, the following policy recommendations are proposed to enhance the role of environmental protection tax in promoting the efficiency of urban green development: 1) Refine the environmental protection tax system and deepen its reform process. Increase the tax rate standards, strengthen environmental regulations, and fully leverage the incentive potential of environmental protection tax for urban green development efficiency. Implement differentiated tax rates, fully considering regional and corporate heterogeneity, and establish tailored environmental protection tax rates based on each city's environmental carrying capacity and economic development level. 2) Strengthen the guiding role of industrial structure upgrading by actively promoting industrial restructuring and optimization. Fully leverage the environmental

protection tax's role in advancing industrial transformation through supporting measures such as tax incentives and fiscal subsidies to encourage enterprises to transition toward green, low-carbon industries. Prioritize support for high-tech industries and modern service sectors while driving technological upgrades and resource consolidation in traditional high-pollution industries. 3) Enhance environmental information disclosure and public awareness campaigns. Utilize new media platforms to disseminate environmental knowledge and heighten public attention to environmental issues. Establish regular mechanisms for public participation in environmental governance, such as public oversight channels for environmental tax collection, fostering a collaborative governance framework among government, enterprises, and the public. 4) Given the spatial spillover effects of the environmental protection tax, strengthen interregional policy coordination and cooperation. Establish cross-regional environmental governance coordination mechanisms to share pollution monitoring data and technical resources, prevent pollution transfer and free-riding, and achieve coordinated green development across regions. 5) Integrate with other environmental policy tools (e.g., carbon emissions trading, green finance) to create multidimensional policy synergies. Simultaneously, enhance support for corporate green technological innovation by establishing dedicated funds to reduce transition costs for enterprises, ensuring the long-term effectiveness of environmental protection tax policies.

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# The Dilemmas in Exercising the Right to Explanation of Automated Decision-Making Algorithms and Their Resolution Paths

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**Abstract:** With the widespread application of artificial intelligence technology, automated decision-making algorithms play a crucial role in fields such as justice, administration, and commerce. However, the “black box” nature of algorithms has given rise to numerous issues, leading to the emergence of the right to algorithm explanation. Nevertheless, this right encounters dilemmas during its exercise, including the complexity of algorithm technology, insufficient expertise among explaining entities, and difficulties in understanding for the counterparties. This paper delves into these dilemmas and proposes resolution paths from multiple dimensions such as technology, law, and institutions, including optimizing algorithm technology, clarifying the responsibilities of explaining entities, improving legal systems, and constructing a multi-stakeholder governance mechanism. The aim is to ensure the effective exercise of the right to algorithm explanation and safeguard fairness, justice, and social order.

**Keywords:** Automated Decision-Making; Right to Algorithm Explanation; Dilemmas in Exercising Rights; Resolution Paths

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## 1.Introduction

In the digital age, automated decision-making algorithms, with their advantages of efficiency and precision, are widely applied across various fields such as justice, administration, and commerce. In the judicial realm, algorithms assist in sentencing and risk assessment, enhancing judicial efficiency. In the administrative sphere, automated administrative approvals and public credit evaluations improve administrative effectiveness. In the commercial sector, personalized recommendations and dynamic pricing bolster market competitiveness. However, the “black box” characteristic of algorithms makes it difficult to directly observe their decision-making processes and reasoning bases. Once problems arise, tracing the causes becomes challenging, sparking public doubts about the rationality of decision outcomes and undermining the authority and credibility of relevant systems. To address this issue, the right to algorithm explanation has emerged. Yet, in practice, its exercise faces numerous dilemmas, necessitating the exploration of effective resolution paths.<sup>[1]</sup>

## 2.Overview of the Right to Explanation of Automated Decision-Making Algorithms

### 2.1 Definition of the Right to Algorithm Explanation

The right to algorithm explanation refers to the right of a data subject to raise objections to an algorithm user and request an explanation of a specific automated decision made by an artificial intelligence algorithm when that decision has a significant



legal or economic impact on the data subject. It also includes the right to request data updates or error corrections. This right empowers data subjects to understand the basis, process, and results of algorithm-based decisions, serving as a vital means to safeguard their legitimate rights and interests.

## **2.2 Importance of the Right to Algorithm Explanation**

### **2.2.1 Safeguarding Fairness and Justice**

Algorithm-based decisions may be biased and discriminatory. For instance, algorithms based on historical data may perpetuate past prejudices, leading to unfair treatment of specific groups.<sup>[2]</sup> The right to algorithm explanation enables data subjects to understand the reasons behind decisions and determine whether unfair factors exist, thereby protecting their legitimate rights and interests and promoting social fairness and justice.

### **2.2.2 Enhancing Trust**

In an era of widespread algorithm application, public trust in algorithms is of utmost importance. If the decision-making processes of algorithms remain opaque, the public will find it difficult to understand their decision bases, leading to suspicion and mistrust. By exercising the right to algorithm explanation, data subjects can gain insights into how algorithms operate, thereby enhancing their trust in algorithms and increasing their acceptance of relevant systems and services.

### **2.2.3 Promoting Algorithm Optimization**

The right to algorithm explanation requires algorithm users to provide decision explanations to data subjects, which helps identify problems and deficiencies in algorithms. Algorithm developers can then optimize and improve algorithms based on feedback from these explanations, enhancing their accuracy and reliability and driving the continuous development of algorithm technology.<sup>[3]</sup>

## **3. Dilemmas in Exercising the Right to Explanation of Automated Decision-Making Algorithms**

### **3.1 Explanation Dilemmas Due to the Complexity of Algorithm Technology**

#### **3.1.1 Complexity of Algorithm Structures**

Algorithms are methods or processes for solving problems, possessing important attributes such as input, output, finiteness, determinacy, and feasibility. In automated decision-making, algorithms typically adopt complex structures, breaking down complex problems into multiple smaller parts and then integrating the results. With the continuous evolution of digital technology, algorithms are becoming increasingly sophisticated, with higher degrees of modularity.<sup>[4]</sup> The interactions among various parts are becoming difficult to predict, increasing the difficulty and uncertainty of explanations. For example, deep learning algorithms perform feature extraction and decision-making through multi-layer neural networks, making their decision-making processes difficult to explain in a straightforward manner.

#### **3.1.2 Autonomous Learning Capability of Algorithms**

Modern algorithms possess powerful autonomous learning abilities, enabling them to mine information and learn patterns from large volumes of data and continuously optimize decision-making. However, this autonomous learning process makes algorithm-based decisions even more elusive. Algorithms transform data into a latent space and calculate how to infinitely approach a set goal, but it is difficult to provide direct reasons. Take AlphaGo as an example; it defeated world-class Go players through autonomous learning, but even its computer engineers found it challenging to provide a detailed explanation of its decision-making processes, as it exceeded their understanding and control.

### **3.2 Dilemmas Due to Insufficient Expertise Among Explaining Entities**

#### **3.2.1 Dilemmas Faced by Administrative Agencies**

In automated administration, algorithms are often developed by professional technology companies and purchased and used by administrative agencies. Administrative agency staff mainly apply algorithms for decision-making and are not familiar with the principles and technical details of algorithms. Moreover, complex algorithms are usually completed by multiple programmers, with each programmer responsible for only a part of the algorithm. Few can fully explain all the details of an algorithm. Therefore, administrative agencies find it difficult to provide professional explanations of algorithms and cannot accurately explain the specific operation processes of algorithms when relying on them for administrative actions.

### **3.2.2 Dilemmas Faced by Commercial Platforms**

Commercial platforms play a significant role in automated decision-making but also face the issue of insufficient expertise. Some small commercial platforms may lack professional algorithm teams and have limited understanding and mastery of algorithms. Even large commercial platforms with professional algorithm personnel may be unwilling or unable to provide detailed algorithm explanations to users due to the complexity of algorithms and commercial confidentiality considerations.<sup>[5]</sup> Additionally, in the pursuit of commercial interests, commercial platforms may overlook the importance of algorithm explanations and respond perfunctorily to user requests for explanations.

### **3.3 Dilemmas Due to Difficulties in Understanding for the Counterparties**

#### **3.3.1 Lack of Professional Knowledge**

Algorithms involve knowledge from multiple fields such as computer science, mathematics, and statistics, exhibiting a high degree of professionalism and complexity. Most counterparties lack relevant professional knowledge backgrounds and find it difficult to understand the technical details and decision-making processes of algorithms. Even if algorithm users provide detailed explanations, counterparties may not be able to grasp their meanings, significantly reducing the effectiveness of explanations. For example, concepts such as neural networks and machine learning in algorithms are often unknown to ordinary counterparties, preventing them from obtaining useful information from explanations.

#### **3.3.2 Lack of Interest and Motivation to Understand**

In some cases, counterparties are not interested in algorithm explanations, especially when the explanation content does not involve their core interests. Even if algorithm explanations are provided, counterparties may find them dull and difficult to understand, thus giving up further exploration. Moreover, disruptive disclosures by algorithms, such as providing excessive irrelevant information or using complex technical terms, increase the difficulty of understanding for counterparties, making them even less willing to comprehend and accept algorithm explanations.

### **3.4 Dilemmas Due to Inadequate Legal Systems**

#### **3.4.1 Unclear Definitions of Right and Obligation Subjects**

Currently, Chinese laws do not clearly define the right and obligation subjects of the right to algorithm explanation. Although Article 24, Paragraph 3 of the Personal Information Protection Law stipulates that when an automated decision-making method is used to make a decision that has a significant impact on an individual's rights and interests, the individual has the right to request an explanation from the personal information processor, detailed regulations on the specific scope of right subjects and the specific responsibilities of obligation subjects are lacking. This leads to problems such as unclear definitions of right and obligation subjects and mutual shirking of responsibilities during the actual exercise of the right to algorithm explanation.

#### **3.4.2 Lack of Explanation Standards and Procedures**

Laws do not clearly stipulate the standards and procedures for algorithm explanations, leaving the exercise of the right to algorithm explanation without norms and constraints. Questions such as to what extent explanations should be provided, in what ways, and within what time frames remain unanswered. This may result in non-standardized and incomplete explanations provided by algorithm users, or even perfunctory responses, failing to meet the needs of counterparties. At the same time, there is also a lack of supervision and review mechanisms for algorithm explanations, making it difficult to ensure the authenticity and rationality of explanations.

## **4. Resolution Paths for the Dilemmas in Exercising the Right to Explanation of Automated Decision-Making Algorithms**

### **4.1 Optimizing Algorithm Technology to Enhance Explainability**

#### **4.1.1 Developing Explainable Algorithms**

Algorithm developers should increase their investment in the research and development of explainable algorithms and make explainability one of the important goals of algorithm design. For example, developing rule-based algorithms, whose decision-making processes are based on clear rules and logic and are easy to understand and explain; or adopting model explainability techniques to explain complex machine learning models, such as through feature importance analysis and

decision tree visualization, to help users understand the decision-making bases of models.

#### **4.1.2 Establishing Algorithm Transparency Standards**

Formulating unified algorithm transparency standards to clarify the content and extent of information that algorithms should disclose. For example, requiring algorithms to provide key information such as the sources of input data, processing procedures, and decision rules, enabling counterparties to understand the basic operation modes of algorithms. At the same time, establishing an algorithm transparency assessment mechanism to regularly assess and supervise the transparency of algorithms, ensuring that they meet transparency standards.

### **4.2 Clarifying the Responsibilities of Explaining Entities and Enhancing Their Explanation Capabilities**

#### **4.2.1 Strengthening the Responsibilities of Administrative Agencies**

Administrative agencies should strengthen their learning and understanding of algorithms and improve their algorithm literacy. This can be achieved by conducting training sessions and introducing professional talents to enhance the cognitive and explanatory capabilities of administrative agency staff regarding algorithms. At the same time, establishing a communication and coordination mechanism between administrative agencies and algorithm developers, requiring algorithm developers to provide detailed algorithm documentation and technical descriptions, so that administrative agencies can better understand and explain algorithms. Additionally, administrative agencies should establish and improve algorithm explanation systems, clarifying explanation procedures and responsibilities to ensure timely and accurate explanations when receiving explanation requests from counterparties.

#### **4.2.2 Regulating the Behavior of Commercial Platforms**

Commercial platforms should establish correct values, prioritize user rights and interests, and attach importance to algorithm explanation work. Establishing a sound algorithm explanation mechanism, clarifying the responsible departments and personnel for explanations, and ensuring timely responses and detailed explanations when users request explanations. At the same time, strengthening the management and supervision of algorithm development teams, requiring algorithm developers to focus on the explainability of algorithms during the development process and provide necessary technical support. Moreover, commercial platforms should actively communicate with users, understand their needs and feedback, and continuously improve algorithm explanation work.

### **4.3 Improving Explanation Methods to Enhance Counterparty Understanding**

#### **4.3.1 Using Easy-to-Understand Explanation Languages**

When providing explanations, algorithm users should avoid using professional terms and complex technical languages and instead use easy-to-understand, concise, and clear languages for explanations. They can use examples and metaphors to transform abstract algorithm concepts into concrete and easily understandable content. For example, comparing the decision-making process of an algorithm to a chef cooking a dish, where input data is the ingredients, the algorithm is the recipe, and the decision result is the finished dish, making it easier for counterparties to understand the basic operation modes of algorithms.

#### **4.3.2 Providing Personalized Explanation Services**

Based on the knowledge levels and needs of counterparties, personalized explanation services should be provided. For counterparties with different backgrounds, different explanation methods and depths can be adopted. For example, for counterparties with a certain level of professional knowledge, more detailed and in-depth technical explanations can be provided; for ordinary counterparties, simple and clear summary explanations can be offered. At the same time, through interactive methods, counterparties can be allowed to participate in the explanation process, and their questions can be answered promptly to improve the effectiveness of explanations.

### **4.4 Improving Legal Systems to Provide Institutional Guarantees**

#### **4.4.1 Clarifying Definitions of Right and Obligation Subjects**

Laws should clearly define the right and obligation subjects of the right to algorithm explanation. Right subjects should include all counterparties adversely affected by automated decision-making, whether in the judicial, administrative, or

commercial fields. Obligation subjects should include algorithm users, such as administrative agencies and commercial platforms. At the same time, clarifying the specific responsibilities and obligations of obligation subjects, such as the time, method, and content of providing explanations, to ensure clear definitions of right and obligation subjects.

#### **4.4.2 Formulating Explanation Standards and Procedures**

Formulating detailed algorithm explanation standards and procedures to regulate the exercise of the right to algorithm explanation. Explanation standards should include requirements for the completeness, accuracy, and clarity of explanations to ensure that explanations meet the needs of counterparties. Explanation procedures should clarify the ways in which counterparties can request explanations, the response time of algorithm users, and the methods of providing explanations to ensure the orderly exercise of the right to explanation. At the same time, establishing a supervision and review mechanism for algorithm explanations to evaluate and assess the explanations provided by algorithm users, ensuring their authenticity and rationality.

#### **4.4.3 Establishing a Legal Liability System**

Establishing a sound legal liability system for the right to algorithm explanation to punish violations of algorithm explanation obligations. When algorithm users refuse to provide explanations, provide false explanations, or explanations that do not meet standards, they should bear corresponding legal responsibilities, such as administrative penalties and civil compensation. Through legal constraints, algorithm users are prompted to conscientiously fulfill their algorithm explanation obligations and protect the legitimate rights and interests of counterparties.

### **4.5 Constructing a Multi-Stakeholder Governance Mechanism to Form Regulatory Synergy**

#### **4.5.1 Strengthening Government Supervision**

The government should strengthen its supervision of automated decision-making algorithms and establish a sound algorithm supervision system. Setting up specialized algorithm regulatory agencies responsible for the comprehensive supervision of the development, use, and explanation of algorithms. Strengthening the review and assessment of algorithms to ensure that they comply with laws, regulations, and ethical and moral requirements. At the same time, providing training and guidance to algorithm users to enhance their legal awareness and sense of responsibility.

#### **4.5.2 Encouraging Social Supervision**

Encouraging the public, media, industry associations, and other stakeholders to supervise automated decision-making algorithms. Establishing a public reporting mechanism to encourage the public to report and complain about problems with algorithms. The media should play a role in public opinion supervision, promptly exposing unreasonable and unfair phenomena related to algorithms. Industry associations should formulate industry norms and standards to guide algorithm users in complying with laws, regulations, and industry ethics, promoting the healthy development of the algorithm industry.

#### **4.5.3 Promoting International Cooperation**

Automated decision-making algorithms are global technologies and applications, requiring strengthened international cooperation and exchanges. Countries should jointly formulate international rules and standards for algorithm governance and enhance cooperation in algorithm supervision, technology research and development, and talent cultivation. Through international cooperation, jointly addressing the challenges and problems brought about by algorithms and promoting the improvement of the global algorithm governance system.

## **5. Conclusion**

The right to explanation of automated decision-making algorithms is an important means to safeguard the legitimate rights and interests of data subjects and maintain social fairness and justice. However, in practice, its exercise faces numerous dilemmas, including the complexity of algorithm technology, insufficient expertise among explaining entities, difficulties in understanding for counterparties, and inadequate legal systems. To resolve these dilemmas, measures need to be taken from multiple dimensions such as technology, law, and institutions, including optimizing algorithm technology, clarifying the responsibilities of explaining entities, improving explanation methods, improving legal systems, and constructing a multi-stakeholder governance mechanism. Through the implementation of these paths, the effective exercise of the right to algorithm explanation can be ensured, promoting the healthy development of automated decision-making algorithms and

driving social progress and prosperity. In future development, we also need to continuously monitor the development and changes of algorithm technology and timely adjust and improve relevant policies and measures to adapt to new challenges and demands.

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# Analysis on the Impact of Digital Finance on Carbon Emissions under the Background of “Double Carbon”

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**Abstract:** Under the background of frequent global extreme climate problems, achieving the goal of peak carbon dioxide emissions and carbon neutrality has become the main policy to promote the process of carbon emission reduction. At the same time, as a new financial form, digital finance has gradually increased its impact on carbon emissions. Through in-depth analysis of the multiple influence mechanisms between digital finance and carbon emissions, this paper discusses the direct and indirect roles of digital finance in promoting the development of low-carbon economy. However, digital finance also faces many challenges in the process of carbon emission application, such as the lagging digital system of carbon finance market, insufficient innovation of digital products of carbon finance, and insufficient understanding and participation of all parties. Therefore, in order to give full play to the positive role of digital finance in reducing carbon emissions, it is necessary to strengthen the construction of digital system of carbon finance market, speed up the design of digital products of carbon finance and improve the understanding and participation of all parties. This paper has important theoretical and practical significance for understanding and using digital finance to promote the development of low-carbon economy.

**Keywords:** “Double Carbon” Target; Digital Finance; Carbon Emissions; Carbon Finance

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## 1.Introduction

Destructive human activities such as industrialization and the extensive use of fossil fuels have caused frequent global extreme climate problems. Among them, a large number of greenhouse gas emissions pose a serious threat to the global ecosystem and human survival. Therefore, achieving the goal of carbon emission reduction is not only the need to protect the earth's ecological environment, but also the inevitable requirement to achieve sustainable development<sup>[1]</sup>. As one of the largest emitters of greenhouse gases in the world, China bears an important responsibility in tackling climate change. In order to promote the process of carbon emission reduction, it has become an important strategy for China to achieve the “double carbon” goal of peak carbon dioxide emissions and carbon neutrality, which will promote the adjustment of China's industrial structure and energy structure, promote the research and development and application of green low-carbon technologies, improve energy utilization efficiency and reduce greenhouse gas emissions<sup>[2]</sup>. As a new model of modern financial services, digital finance provides new solutions and financial support for carbon emission reduction and gradually plays an important role in the process of carbon emission reduction<sup>[3]</sup>. Based on the goal of “double carbon”, this paper explores the mechanism of the impact of digital finance on carbon emission reduction from both direct and indirect perspectives, deeply analyzes the challenges faced by digital finance in carbon emission application, and finally puts forward relevant suggestions on enabling



carbon emission by digital finance, with a view to providing theoretical support and practical guidance for the realization of the goal of “double carbon”.

## **2.The multiple impact mechanism of digital finance on carbon emissions**

### **2.1 Direct influence**

First, innovative investment and financing channels. By providing innovative investment and financing channels for green and low-carbon projects, digital finance enables enterprises and consumers to obtain green financial products and services more conveniently, helps investors better understand and invest in green technology projects, evaluates and screens green technology projects, and guides funds to flow to low-carbon and environmentally-friendly carbon emission projects and gather in the field of green technology. It can not only give priority to providing financial support for projects or enterprises with low carbon emissions, but also provide investors with green investment choices, thus promoting the transformation of the whole society into a low-carbon economy. Second, reduce the intensity of energy consumption. Digital finance reduces the use of paper documents and physical bank outlets by optimizing financial services and improving financial efficiency, and through digital means such as Internet payment and mobile payment, thus reducing the energy consumption intensity of financial activities<sup>[4]</sup>. Third, improve efficiency and reduce costs. Digital financial platform has Internet financial platform and intelligent investment. Through intelligent service means, traditional financial transactions and financial service processes are simplified, green financial products can be traded and transferred more conveniently, the financing efficiency of green financial market is improved, and the cost of financial transactions involved in carbon emission projects is reduced, so as to accelerate the process of carbon emission reduction.

### **2.2 Indirect effects**

From the perspective of consumption patterns. Digital finance can reduce carbon emissions by promoting greener consumption patterns. The convenient payment method provided by digital finance can reduce dependence on traditional physical currency and bank cards, thus reducing resource consumption and environmental pollution related to these physical media. In addition, convenient payment methods such as mobile payment accelerate customer decision-making, drive customer demand and improve customer consumption patterns. Some payment platforms have also launched a green point system to encourage users to use green travel modes or buy environmentally-friendly products, and promote green consumption through the point reward mechanism<sup>[5]</sup>. From the perspective of industrial structure. By supporting green technology innovation, digital finance can accurately assess the environmental impact of projects, effectively integrate various information resources into production decisions, promote the restructuring of industrial systems, and promote the transfer of labor-intensive industries to environmentally friendly technology-intensive industries, and improve the efficiency of resource allocation. Technological progress can not only improve energy efficiency, but also reduce energy consumption and carbon emission intensity during manufacturing<sup>[6]</sup>.

## **3.challenges faced by digital finance in the application of carbon emissions**

### **3.1 carbon financial market digital system lags behind**

Compared with developed countries, China's low-carbon financial system has been formed slowly, and the development of low-carbon finance faces many challenges. Moreover, the lag of the digital system of carbon finance market also reflects that the impact of digital finance on carbon emissions is still weak. First of all, low-carbon finance is a new financial development mode, and commercial financial institutions are cautious about economic needs such as loans involving low-carbon economy, which makes the digital development of low-carbon finance lack the support of financial institutions, resulting in a poor financing environment for digital low-carbon finance and a lack of sufficient development momentum. Secondly, the digital system of carbon finance market in China is relatively backward, and the relevant rules and mechanisms for the application of digital finance have not been fully established, and there are problems such as regulatory gaps and overlapping, which limit the development of carbon finance and the application of digital finance in carbon emissions to some extent. At the same time, because the price of carbon emission rights is affected by the relationship between market supply and demand, there will be corresponding fluctuations, which makes it difficult for all parties involved in carbon finance to plan and predict the benefits

and risks of carbon finance business. It may lead to market chaos and risk events. Therefore, although digital technology provides convenience for the collection and processing of carbon emission data, in practice, the application of digital finance in carbon emission still faces some challenges.

### **3.2 carbon finance digital product innovation is insufficient**

Due to the late start of carbon financial market, domestic enterprises and financial institutions lack a deep understanding of low-carbon economic operation mode, social benefits and other aspects, and lack awareness of carbon resources trading. To a certain extent, domestic enterprises, commercial banks or financial institutions have a single category of digital financial products in carbon emission reduction, and the types and quantities are relatively small, and there is still a lack of characteristic digital financial products for carbon emission projects, which cannot meet the diversified needs of the market. Although some financial institutions have initially developed digital financial products for carbon emission reduction, compared with diversified digital financial products around the world, China's carbon financial products are difficult to meet the market demand in terms of quantity and function, which leads to insufficient activity of the carbon financial market and affects its attractiveness and influence. Moreover, in terms of innovation, digital financial products aimed at carbon emission reduction are weak in innovation and lack new carbon financial products with high added value and market competitiveness. In addition, the government's support for the innovation of carbon financial products is insufficient, and the incentive measures are insufficient, which leads to the lack of sufficient motivation for financial institutions and enterprises to promote the digital innovation of carbon financial products.

### **3.3 insufficient understanding and participation of all parties.**

For a long time, environmental education has not penetrated into all levels of society, and the popularity of carbon finance market is not high. As a result, most domestic financial institutions have limited understanding of low-carbon financial business with carbon emissions and its impact on climate change, which makes enterprises and the public have limited awareness and acceptance of carbon financial products. It takes time and patience to change the long-term consumption habits with high energy consumption and high carbon emissions. Friction and resistance in the process of transformation make it difficult for the public to practice a low-carbon lifestyle. At the same time, low-carbon lifestyles and green financial products require the public and all participants to bear additional economic costs in the short term. Because buying energy-saving appliances or choosing green products means increasing additional initial investment, and the research and development and promotion of high-end green technologies need a long period, it is difficult for enterprises to fully realize the transformation of production mode in a short period of time. Due to the contradiction between personal interests and environmental protection objectives, all participants will give priority to traditional products or production modes with lower costs when facing economic pressure. In addition, the potential risks of digital financial products and green financial products also deter some participants. Digital financial products and green financial products, as the products of new national policies, belong to emerging fields. In addition, the lack of financial knowledge and limited understanding of new digital green financial products lead to low awareness and participation, and all participants prefer traditional and familiar financial products in investment selection.

## **4.digital finance to enable carbon emission reduction countermeasures and suggestions**

### **4.1 Digital system construction of carbon financial market**

At the production level, improve the energy efficiency of digital financial infrastructure. The green transformation of digital financial data center is the key step, and the data center should adopt the latest energy-saving equipment and advanced cooling technology. At the same time, the intelligent management system is introduced into the production enterprises, the energy efficiency evaluation and certification system is established, and through real-time monitoring and dynamic adjustment of the running state and working mode of equipment, excessive cooling and waste of resources are avoided, refined energy consumption control is realized, and energy consumption is further reduced. In addition, we will optimize the allocation of credit resources through digital technology, improve the technology and finance system, promote the development of green and low-carbon technology enterprises, and then promote carbon emission reduction. At the consumption level, establish a comprehensive carbon market database to promote the digital transformation of the carbon financial market. Use big data,

artificial intelligence and other technologies to improve the efficiency and convenience of financial services and develop an intelligent carbon financial trading platform. Moreover, it is necessary to establish a carbon pricing trading system, set up a carbon quota reservation mechanism and serve the carbon market stabilization fund, and use digital finance to improve the flexibility and efficiency of the carbon trading market. Through digital finance, we will continuously optimize the market transaction process, improve the flexibility and efficiency of the carbon trading market, reduce transaction costs, and improve the market competitiveness of carbon financial products. At the regulatory level, establish a sound regulatory system for the carbon financial market, and formulate and improve relevant laws and regulations to ensure fairness, transparency and standardization of the market. But also strengthen the supervision of carbon financial market, prevent the occurrence of improper behaviors such as market manipulation and insider trading, and protect the legitimate rights and interests of investors.

#### **4.2 Accelerate the design of carbon finance digital products**

First, many digital green financial products have complicated structures and asymmetric information, which makes investors feel confused when investing and choose traditional financial products with better understanding. Financial institutions can design more green bonds and funds similar to traditional products, which will lower the public's understanding threshold and enable investors to clearly understand the direction of capital use and environmental benefits. Second, strengthen top-level design and innovative ideas. Financial institutions should strengthen the top-level design, actively practice the ESG development concept, combine the design of carbon financial digital products with the national carbon neutrality goal, and clarify the strategic direction of product design. Third, promote the innovation of carbon financial products and services. Encourage financial institutions to develop more innovative carbon financial products and services, and provide data support for the design of carbon financial digital products. Research and develop innovative financial derivatives such as carbon futures and carbon options, and financing tools such as green credit and green bonds to meet the diversified needs of the market. Fourth, design the product line around the carbon trading market. Use blockchain technology to build the upstream and downstream connection of carbon trading, and take digital finance to empower the carbon trading market as a breakthrough to form a carbon financial product system with digital technology content. The product line constructed by fully displaying the carbon activity map as the underlying technology can completely match and support the operation of the carbon market.

#### **4.3 Improve the awareness and participation of all parties.**

The first is to enhance public awareness and participation. Strengthen publicity and education, publicize the important role of digital finance in carbon emission reduction through government, media, enterprises and other channels, and improve public awareness and acceptance of digital finance. By popularizing carbon finance knowledge, we will guide the public to actively participate in carbon trading and investment, and encourage enterprises and individuals to buy and sell carbon emission rights through carbon trading platforms, thus forming a good atmosphere for all people to participate in emission reduction. The second is to provide economic incentives. Most participants often face the pressure of economic cost when choosing green products. The government and enterprises can jointly launch a series of economic incentives. By providing direct financial subsidies, the purchase cost of green products can be reduced and the economic burden of the public can be reduced. The third is to enhance the acceptance of green financial products by all parties. Financial institutions should strengthen the transparency of digital finance, regularly disclose the operation of green financial products and environmental protection achievements, and enhance public trust and investment confidence through detailed reports and data. Fourth, the government can introduce relevant policies to encourage and support financial institutions to develop digital finance business, promote the application of digital finance in carbon emission projects or wider fields, and encourage all parties to practice low-carbon lifestyles. The fifth is to strengthen cooperation and sharing. Simplify the financial service process through digital means, reduce unnecessary links and time-consuming, and improve service efficiency. Financial institutions can also carry out cross-border cooperation with environmental protection departments and technology enterprises to jointly promote the application of digital finance in carbon emission reduction. Promote the popularization of green lifestyle, attract more investors to buy and use digital financial products, enhance public participation in environmental protection, and guide consumers to gradually

favor environmental protection consumption patterns.

## 5. Conclusion

Climate change has become a major challenge for all countries in the world, which has a profound impact on natural ecosystems and human living environment. There is a contradiction between environmental benefits and economic efficiency to a great extent, and the feasible solution at present is to ensure the development of green economy. Therefore, China has put forward the “double carbon” goal of achieving peak carbon dioxide emissions and carbon neutrality, and digital finance has important potential and role in the process of achieving the “double carbon” goal. By analyzing the direct and indirect mechanism of digital finance affecting carbon emission, it is found that digital finance plays a significant role in promoting carbon emission reduction and sustainable development. However, digital finance also faces certain challenges in the application of carbon emissions. In order to meet these challenges, this paper puts forward many measures, such as strengthening the construction of digital carbon finance market, speeding up the design of digital carbon finance products and improving the understanding and participation of all parties, which can effectively overcome the challenges of digital finance in carbon emission reduction application. It will not only help China achieve its climate goal and promote the coordinated development of economy and environment, but also provide useful experience and reference for the global response to climate change and achieve the goal of sustainable development.

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# Research on the Innovation and Improvement Pathways of Smart Case Management Mechanisms in Prosecutorial Organs in the New Era

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**Abstract:** With the continuous growth in the number of social cases and the advancement of judicial intelligence reforms, traditional case management models have become increasingly inadequate to meet the demands of high-quality case handling by prosecutorial organs in the new era. This study systematically examines the practical significance of smart case management within prosecutorial institutions and provides an in-depth analysis of key challenges in current mechanisms, including inefficient data sharing, an underdeveloped case allocation system, and insufficient levels of intelligent supervision. By promoting the deep integration of information technology and intelligent systems, strengthening full-process supervision, and cultivating a professionalized case management workforce, prosecutorial organs can effectively enhance the scientific rigor, standardization, and overall efficiency of case management. These efforts hold significant theoretical and practical implications for accelerating the development of smart prosecution and advancing judicial modernization.

**Keywords:** Smart; Case; Management; Pathway

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## 1.Introduction

Case management not only ensures the timely receipt, transfer, and allocation of cases, thereby facilitating prosecutors' case handling and alleviating their workload, but also plays a critical role in safeguarding the right to information, the right to supervision, and the right to participation of defense counsel and involved parties. In this regard, effective case management contributes to enhancing the credibility of prosecutorial organs, fostering a positive judicial image, and significantly improving both the quality and efficiency of case handling. However, with the rapid increase in the number of cases in the new era and the continuous emergence of complex social conflicts and disputes, traditional case management models have become increasingly incapable of meeting contemporary practical demands <sup>[1]</sup>. Consequently, the deep integration of modern technologies such as big data and artificial intelligence into case management has become an urgent necessity. The reform of case management mechanisms within prosecutorial organs constitutes a crucial component of the broader process of judicial intelligence reform <sup>[2]</sup>. The development of smart case management is not only an essential measure for advancing smart prosecution, but also a practical response to the evolving expectations placed on prosecutorial institutions in the new era.



Therefore, in-depth research on smart case management mechanisms in prosecutorial organs is of considerable significance. At present, systematic academic research on this topic remains relatively limited. Existing studies predominantly focus on practical case management operations at the local level, while insufficient attention has been paid to the conceptual framework and developmental pathways of intelligent case management. As a result, smart case management mechanisms have emerged as a pressing and underexplored research area warranting further scholarly attention <sup>[3]</sup>.

Although prosecutorial case management has entered the stage of smart case management in practice, notable shortcomings persist at the legislative level. Relevant laws and regulations remain underdeveloped, and legislative gaps exist in certain areas, creating practical obstacles for both case management personnel and prosecutors. Research on smart case management mechanisms can therefore contribute to improving the legislative framework governing case management, guiding standardized practices, and correcting irregularities in case handling. Moreover, the advancement of smart case management enables the provision of more efficient and higher-quality judicial services, enhances comprehensive supervision throughout the case-handling process, and improves the efficiency of case information disclosure. By strengthening information exchange and data sharing among judicial institutions and establishing integrated database platforms, prosecutorial organs can further enhance overall case-handling effectiveness. A multidimensional analysis of smart case management mechanisms from legislative and judicial perspectives is thus of substantial importance for promoting the modernization of prosecutorial organs and strengthening their case-handling capacity <sup>[4]</sup>.

## **2. An Examination of Problems in Smart Case Management Mechanisms of Prosecutorial Organs**

### **2.1 Inefficient Data-Sharing Mechanisms**

Against the backdrop of the continuous deepening of case informatization, inefficiencies in data-sharing mechanisms have become a major constraint on the improvement of case management effectiveness in prosecutorial organs. On the one hand, some prosecutors exhibit insufficient awareness of the importance of case data entry, limited professional understanding, or inadequate proficiency in system operations during the completion of case cards, resulting in frequent instances of incorrect, missing, or delayed data entry. Due to constraints in staffing and technological resources, case management departments often fail to detect and correct these errors in a timely manner, thereby undermining the completeness and accuracy of case data. On the other hand, when lower-level procuratorates upload data with unresolved quality issues to higher-level institutions, data inaccuracies are further amplified through vertical transmission, significantly increasing the overall difficulty of data governance. From a deeper perspective, these problems stem not only from insufficient professional competence and weak accountability among some prosecutors, but also from inadequacies in internal responsibility implementation and supervisory mechanisms, as well as the absence of unified and detailed data evaluation standards and operational norms. In terms of interdepartmental coordination, although prosecutorial organs have actively promoted data sharing and the construction of big data-driven collaborative platforms with administrative, investigative, and adjudicative bodies in recent years, the lack of a unified and efficient coordinating authority and well-established platform operation mechanisms has prevented effective synergy among departments in areas such as data standards, interface design, and access control. As a result, data silos persist. Moreover, influenced by departmental protectionism, some institutions adopt a cautious or even resistant attitude toward data openness due to concerns over information security and accountability, thereby artificially limiting the scope of data sharing. This ultimately places additional coordination and error-correction burdens on case management departments and undermines overall case-handling efficiency as well as the smooth operation of cross-departmental collaboration <sup>[5]</sup>.

### **2.2 Insufficient Levels of Intelligent Supervision in Case Management**

At present, case management departments continue to face shortcomings in the level of intelligent and refined supervision when performing their oversight functions. Regulatory efforts tend to focus primarily on substantive review and procedural compliance, while relatively limited attention is devoted to the supervision of procedural nodes, case-handling time-limit alerts, dynamic risk control, and preventive and corrective measures before and after case handling. In practice, case quality assessment still relies predominantly on manual cross-review, which is time-consuming and labor-intensive and heavily dependent on the professional competence of reviewers. The retrieval and comparison of relevant case materials are likewise



conducted mainly through traditional manual methods, making it difficult to fully leverage the advantages of information systems in data analysis, risk identification, and intelligent early warning, thereby constraining both supervisory efficiency and precision. Furthermore, some case management personnel lack a clear understanding of their job responsibilities and operational requirements, leading to frequent issues such as missing pages or the omission of key materials during the uploading of case files and legal documents. This reflects the need for further improvement in workflow standardization and accountability awareness. In addition, the informatization and standardization of seized property management remain insufficient, supervisory mechanisms addressing prosecutors' misconduct are not yet fully developed, and the people's supervisor system demonstrates limited participation and effectiveness in practice. A comprehensive supervisory framework characterized by multi-actor collaboration and technology-based support has yet to be fully established. Overall, intelligent supervision in case management remains in a critical transitional phase from an "experience-based manual model" to a "data-driven model," and its functional potential has not yet been fully realized <sup>[6]</sup>.

### **3. Pathways for Improving Smart Case Management in Prosecutorial Organs**

#### **3.1 Actively Innovating Intelligent Case-Handling Support Tools**

Against the backdrop of the continuous advancement of smart prosecution, the active innovation and improvement of intelligent case-handling support tools constitute a critical technological foundation for enhancing both prosecutorial efficiency and judicial quality. Such intelligent tools should comprehensively cover the entire case-handling process, ranging from case acceptance and document entry to evidence review and the preparation of legal documents, thereby enabling automated and standardized information processing. At present, although some procuratorates have introduced document entry and intelligent document-generation tools, their practical effectiveness remains constrained by the maturity of algorithms and the scale of training datasets. In particular, recognition accuracy remains inadequate in cases involving complex factual circumstances and specialized legal terminology, resulting in relatively high error rates that undermine usability. With respect to intelligent case file review, existing systems still exhibit deficiencies in mobile-device compatibility and in functions such as text copying, annotation, and key-point marking, making it difficult to accommodate prosecutors' fragmented and mobile work patterns. Coordinated upgrades of software and hardware are therefore urgently needed to enhance system practicality. In the evidence review stage, the analysis of non-written evidence—such as audio and video recordings—continues to rely predominantly on manual listening and viewing, which is time-consuming and prone to oversight. Accelerating the application of speech recognition, image recognition, and related technologies in the judicial field is thus essential to convert non-written evidence into searchable and comparable textual data and to integrate such data into unified case management systems. In addition, greater emphasis should be placed on the development of intelligent guidance and decision-support tools. By leveraging rule databases, case repositories, and risk-alert modules, these tools can provide prosecutors with procedural guidance, evidentiary review points, and legal application suggestions, thereby enhancing the standardization of case handling while fully preserving judicial independence <sup>[7]</sup>.

#### **3.2 Improving the Scientific Design and Operation of Case Allocation Mechanisms**

A scientific and impartial case allocation system serves as a fundamental institutional guarantee for the standardized exercise of prosecutorial power and the enhancement of case-handling efficiency. The prevailing model—characterized by random allocation as the primary method and designated allocation as a supplementary mechanism—generally reflects principles of procedural fairness and power restraint. However, deficiencies persist in practice, including inconsistent rules and excessive discretionary flexibility in implementation. In the absence of unified national standards, disparities exist among regions and procuratorates with respect to allocation conditions, adjustment scenarios, and operational procedures, which may give rise to arbitrariness and non-standard practices. To address these issues, it is necessary for the Supreme People's Procuratorate to formulate unified and scientifically grounded case allocation rules. Such rules should clearly define allocation principles, applicable scopes, and exceptional circumstances, while incorporating factors such as case type, workload, and prosecutors' professional expertise into algorithmic models. This would ensure transparency, dynamic balance, and full traceability throughout the allocation process, thereby reducing opportunities for undue human intervention at the institutional level. In practical implementation, the random allocation mechanism should be strictly enforced, with designated allocation

limited to clearly defined conditions and subject to rigorous approval procedures. Information systems should automatically record allocation rationales and operational traces, enabling both internal and external oversight and enhancing trust among prosecutors and the public in the objectivity and fairness of case allocation.

### **3.3 Establishing an Intelligent Supervision and Constraint System for Case Management**

The establishment of an intelligent supervision and constraint system for case management represents a crucial pathway for transforming oversight from post hoc correction to ex ante prevention and in-process control. Throughout case handling, information systems should be fully utilized to implement automated supervision over time limits, procedural nodes, and document formats. Risks such as delays, procedural anomalies, and formatting errors should trigger timely alerts and be incorporated into performance evaluation systems to form effective accountability mechanisms. At critical decision-making stages—such as case filing, prosecution decisions, and non-prosecution determinations—the system should embed standardized verification and reminder functions to promptly alert prosecutors to procedural noncompliance or potential risks, thereby preventing defective cases. At the same time, big data analytics and intelligent algorithms should be employed to conduct comprehensive assessments of case types, processing cycles, and risk distribution, enabling the early identification of integrity risks, quality risks, and management risks, and enhancing the foresight and precision of supervision. In terms of data governance, real-time monitoring and dynamic correction mechanisms should be established to promptly identify and rectify incorrect or missing data entries, thereby improving data authenticity and integrity and preventing distorted data from undermining management decisions. To ensure effective system operation, dedicated process supervisors should be appointed to conduct routine inspections, oversee rectification efforts, compile key statistics, and perform periodic audits. This “system-based supervision plus manual review” dual assurance mechanism can facilitate precise oversight across all procedural stages and ensure comprehensive coverage of critical case-handling processes.

### **3.4 Establishing an Intelligent Supervision and Constraint System for Case Management**

Building a professional and multidisciplinary intelligent case management workforce is the fundamental guarantee for promoting the high-quality development of case management. In view of the comprehensive nature of case management in supervision, service provision, and data governance, personnel should be rationally allocated according to functional requirements. The workforce should be categorized into supervision and management personnel, case-handling support staff, comprehensive business personnel, and information technology specialists, with clearly defined responsibilities to form a coordinated and efficient working structure. To enhance overall professional competence, a normalized training mechanism should be established, providing tiered and specialized training focused on information system operation, case process management, data analysis, and risk prevention and control. Through the formulation of unified operational manuals and the implementation of practical assessments, it can be ensured that personnel are “certified for duty and perform their responsibilities in a standardized manner.” At the same time, incentive and support mechanisms should be improved by means of merit-based evaluations, professional competitions, and achievement showcases, so as to stimulate work motivation and innovative vitality and foster a positive atmosphere of mutual learning and healthy competition. At the level of professional development, case management personnel should be encouraged to participate in frontier research projects, conduct empirical analyses and theoretical syntheses based on case data, and feed research outcomes back into practice in the form of academic papers and research reports. Meanwhile, it is essential to establish strong brand awareness for intelligent case management, strengthen the independence and central coordinating role of case management departments within prosecutorial functions, and fully leverage big data and intelligent technologies to enhance precision monitoring, risk early warning, and case quality evaluation. In addition, exchanges and experience-sharing among procuratorial organs at different levels should be strengthened. By integrating regional characteristics, intelligent case management brands with distinctive local features can be developed, using demonstration and benchmarking effects to continuously improve the overall level of case management.

## **4. Conclusion**

As a critical component of the procuratorial organs’ efforts to advance judicial intelligence and modernization, intelligent case management is not only a practical requirement for improving the efficiency and quality of case handling, but also an inevitable choice for enhancing public trust in procuratorial work and ensuring judicial fairness. At present, intelligent

case management still faces numerous challenges in areas such as data sharing, case assignment standards, and intelligent supervision. Addressing these issues requires adherence to top-level design, the formulation of unified case assignment rules, the improvement of intelligent auxiliary tools, the construction of full-process supervision and early-warning systems, and intensified efforts in cultivating professional teams and developing local brands. Through the continuous deepening of the application of emerging technologies such as big data and artificial intelligence in case management, and by further improving coordination mechanisms and professional support systems, it is possible to substantially enhance the standardization and intelligence level of case management, thereby promoting high-quality development and the modernization of judicial capacity of procuratorial organs in the new era.

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# Empirical Research on Digital Technology Empowering Rural Industrial Diversity: An Analysis Based on County-Level Panel Data

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**Abstract:** Against the backdrop of the deep integration between the new round of technological revolution and the rural revitalisation strategy, digital technology has emerged as a crucial engine driving the diversified development of rural industries. This study employs Propensity Score Matching-Difference in Differences (PSM-DID) methodology, utilising panel data from 95 counties across China between 2018 and 2023, to empirically examine the impact of digital technology on rural industrial diversity and its underlying mechanisms. Findings indicate that the adoption of digital technology significantly enhances county-level industrial diversity, with an average effect of approximately 5.92%, a result that remains robust across multiple tests. Heterogeneity analysis reveals that the enabling effects of digital technologies are more pronounced in economically developed counties with larger populations, reflecting the moderating roles of infrastructure, factor agglomeration, and market scale on technological impacts. Dynamic effect analysis further indicates that the diversity-enhancing effects of digital technologies exhibit a sustained strengthening trend, consistent with the long-term patterns of technology diffusion and human capital accumulation. This study provides empirical evidence for leveraging digital technologies to empower rural industrial transformation and offers policy insights for advancing digital rural development in a differentiated and systematic manner.

**Keywords:** Digital Technology; Rural Industrial Diversity; County-Level Panel Data; PSM-DID Method; Policy Effects

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## 1. Research Background

Since the turn of the century, China's urbanisation process and rural revitalisation strategy have advanced in tandem, propelling urban-rural relations into a new phase of deep integration. Data from the National Bureau of Statistics indicates that China's urbanisation rate reached 66.2% in 2023, yet the rural resident population remains at 490 million, forming a unique development pattern where "large-scale urbanisation" coexists with "deep rural revitalisation"<sup>[1]</sup>. Against this backdrop, digital technologies centred on 5G, artificial intelligence, big data, and the Internet of Things are emerging as key drivers for reshaping rural industrial structures and resolving development challenges<sup>[2]</sup>.

In 2020, seven ministries including the Cyberspace Administration of China and the Ministry of Agriculture and Rural Affairs jointly issued the Digital Rural Development Strategy Outline, which for the first time established the national strategic objective of "empowering agricultural and rural modernisation through digital technologies"<sup>[3]</sup>. Subsequent policies such as

the Digital Rural Development Guidelines 2.0 and the 14th Five-Year Plan for Digital Economic Development have been rolled out, establishing a comprehensive policy framework for digital rural development covering infrastructure, industrial applications, and governance services<sup>[4]</sup>. Nevertheless, rural industrial development currently faces multiple structural challenges: firstly, a monolithic industrial structure where agriculture dominates output value, with insufficient integration between primary and secondary industries; secondly, impeded factor mobility, with high-quality elements such as talent, capital, and technology tending to flow into cities rather than rural areas; thirdly, short industrial chains characterised by high proportions of primary product processing and weak brand premium capabilities<sup>[5]</sup>. Digital technologies offer new pathways to enhance rural industrial diversity by breaking geographical barriers, optimising resource allocation, and revitalising cultural assets. Consequently, scientifically identifying their impact mechanisms and policy outcomes has become a critical issue in both theoretical and practical domains<sup>[6]</sup>.

## 2. Literature Review

### 2.1 Research on Mechanisms of Digital Technology Empowering Rural Development

Existing research generally holds that digital technology provides a core driving force for rural development by reducing information costs and institutional transaction costs. Wang Yahuai notes that digital technologies can enhance transparency in rural governance and multi-stakeholder coordination efficiency, improve the rural business environment, and create institutional conditions for the two-way flow of factors. Wen Tao and Chen Yiming further propose that the coupling of digital technologies with the “data-technology-scenario” framework can drive the integration and upgrading of agriculture with secondary and tertiary industries, extend value chains, and form a “digital channel” for industrial revitalisation<sup>[7]</sup>.

Within the inclusive development dimension, digital inclusive finance emerged as a research focal point. Chen Yanli’s research based on county-level data from Hunan demonstrated that digital inclusive finance significantly enhances rural financial accessibility, with core coefficients remaining positively significant across multiple robustness tests. However, Sun Shuzhang’s study of Henan counties found no significant direct impact of inclusive finance on industrial restructuring, suggesting that the “finance-industry” transformation requires policy coordination and industrial support systems, highlighting the systemic nature of digital technology empowerment<sup>[8]</sup>.

### 2.2 Empirical Research on Digital Technology and Industrial Diversity

Large-scale county-level studies provide empirical evidence on the industrial effects of digital technologies. Liu Huguang’s analysis of 2011–2022 panel data from 903 counties across 15 provinces reveals that the digital economy promotes urban-rural integration by optimising industrial structures and regulating labour mobility. Tian Ye’s research confirms that urban-rural integration mediates the relationship between the digital economy and rural industrial revitalisation, with this effect influenced by regional characteristics such as the scale of agricultural labour<sup>[9]</sup>.

At the practical case level, field investigations by Yin Yao and Gao Xiao’an indicate that digital technologies must integrate with traditional mechanisms such as village regulations and community organisations to avoid “technological suspension”. Li Qian’s case study of Xuzhou reveals that while digitalisation can drive the integration of rural tourism and industries, uneven infrastructure, talent shortages, and homogenisation continue to constrain outcomes. Concurrently, scholars including Shen Feiwei and Wei Xiaojing highlight shortcomings in digital village development, such as homogenisation, regional development imbalances, and inadequate data governance, necessitating optimisation through rule provision, capacity building, and differentiated implementation<sup>[10]</sup>.

## 3. Research Design

### 3.1 Data Sources and Sample Selection

This study employs counties as the fundamental analytical unit. Considering regional economic development levels and digital infrastructure advancement, a systematic sampling method was used to select 95 representative counties nationwide as the initial sample, covering eastern, central, and western regions. The basic characteristics of the sample are presented in Table 1. Research data were sourced from the 2018–2023 China County Statistical Yearbook, China City Statistical Yearbook, provincial and municipal statistical bulletins, and the National Bureau of Statistics’ public database. Following data cleansing

and matching, a balanced panel dataset was formed.

*Table 1 Distribution of Basic Characteristics of Sample Counties (N=95)*

Characteristic Variable	Category	Frequency	Percentage	Intervention Group (High Digitalisation)	Control Group (Low Digitisation)
Regional Distribution	Eastern Region	42	44.2%	18 (42.9%)	24 (57.1%)
	Central Region	31	32.6%	12 (38.7%)	19 (61.3%)
	Western Region	22	23.2%	8 (36.4%)	14 (63.6%)
Level of Economic Development	High-income group	32	33.7%	15 (46.9%)	17 (53.1%)
	Medium Income Group	41	43.2%	16 (39.0%)	25 (61.0%)
	Low-income group	22	23.2%	7 (31.8%)	15 (68.2%)
Dominant Industry Type	Agricultural Dominance	38	40.0%	11 (28.9%)	27 (71.1%)
	Industrial dominance	35	36.8%	16 (45.7%)	19 (54.3%)
	Service-led	22	23.2%	11 (50.0%)	11 (50.0%)

## 3.2 Variable Definitions and Research Methods

### 3.2.1 Variable Definitions

Dependent Variable: Industry Diversity Index, calculated using an entropy index based on the output value of the three major industries. The value range is  $[0, \ln 3]$ , with higher values indicating greater industry diversity.

Core Explanatory Variable: Interaction term between treatment group and policy timing (treatment  $\times$  post). Treatment group (highly digitalised counties) and control group (lowly digitalised counties) are delineated based on the median fixed-line telephone penetration rate in 2019. The policy timing is defined as the comprehensive implementation of the 2020 Digital Rural Development Strategy Outline.

Control variables: include per capita GDP (log-transformed), registered population (log-transformed), secondary industry share, tertiary industry share, and local fiscal revenue (log-transformed), controlling for differences in county-level economic foundations and factor endowments.

### 3.2.2 Research Methodology

This study employs the Propensity Score Matching-Differences-in-Differences (PSM-DID) method to examine the impact of digital technologies on industrial diversity, following these steps:

- (1) Propensity score matching: Using per capita GDP, registered population, and industrial structure as covariates, a caliper matching approach is employed to pair treatment groups with similar control groups, thereby mitigating selection bias;
- (2) Difference-in-Differences Estimation: Constructing a DID model controlling for individual and time fixed effects to identify the net effect of digital technologies;
- (3) Robustness checks: Validate results by altering matching methods (kernel matching, nearest neighbour matching), adjusting grouping criteria (quantiles, quartiles), and conducting placebo tests (advancing policy implementation to 2019);
- (4) Heterogeneity and dynamic effects analysis: Regressions grouped by economic development level and population size to examine heterogeneity characteristics; test policy effects' temporal evolution patterns via multi-period DID.

## 4. Empirical Analysis

### 4.1 Benchmark Regression and Robustness Checks

#### 4.1.1 Benchmark Regression Results

Following PSM matching, 49 observations across 21 counties (8 treatment, 13 control) were finalised. The benchmark



regression results (Table 2) indicate that the coefficient for the core explanatory variable  $\text{treatment} \times \text{post}$  is 0.035, significantly positive at the 1% level ( $t=5.97$ ,  $p<0.001$ ). This demonstrates that digital technologies significantly enhance rural industrial diversity by approximately 5.92%. Among the control variables, the share of primary industry (coefficient 0.006,  $p < 0.001$ ) and the share of secondary industry (coefficient 0.001,  $p < 0.001$ ) were significantly positive, indicating that industrial structure optimisation exerts a positive influence on diversity. The adjusted  $R^2$  of the model was 0.853, demonstrating good model fit.

Table 2: Benchmark Regression and Robustness Test Results

Variable / Test Type	Baseline Regression	Robustness Test — Alternating Matching Method	Robustness Test — Altering Grouping Criteria	Robustness Test — Placebo Test
	(PSM-DID)	Kernel Matching	Nearest Neighbour Matching	Quartile
Treatment $\times$ Post	0.035***(0.006)	0.036***(0.007)	0.032***(0.008)	0.023*(0.012)
treatment	0.005(0.004)	0.006 (0.005)	0.004(0.005)	0.003 (0.006)
post	0.003 (0.004)	0.004 (0.005)	0.002 (0.005)	0.001 (0.006)
Primary industry share	0.006***(0.001)	0.005***(0.001)	0.006***(0.001)	0.004***(0.001)
Secondary industry share	0.001***(0.000)	0.001***(0.000)	0.001***(0.000)	0.001** (0.000)
Control variables	Yes	Yes	Yes	Yes
Observation Count	49	49	49	49
Adjusted $R^2$	0.853	0.841	0.835	0.812

Note: \*, \*\*, \*\*\* denote significance at the 1%, 5%, and 10% levels respectively; standard errors are shown in parentheses.

#### 4.1.2 Robustness Test Results

Changing matching methods: DID coefficients for kernel matching and nearest neighbour matching were 0.036 ( $p < 0.001$ ) and 0.032 ( $p < 0.001$ ) respectively, both significantly positive and consistent with baseline results;

Changing the grouping criteria: The DID coefficient for quantile grouping was 0.023 ( $p < 0.1$ ), significant at the 10% level; the quartile grouping coefficient was not significant, possibly due to reduced inter-group differences after grouping;

Placebo test: Assuming the policy was implemented in 2019, the DID coefficient was 1.407 and non-significant, indicating no significant effect prior to policy implementation and validating the validity of causal identification.

### 4.2 Heterogeneity and Dynamic Effects Analysis

#### 4.2.1 Heterogeneity Analysis

Regression by economic development level and population size revealed:

Economic Development Level: The DID coefficient for high-income counties was 0.040 ( $p < 0.01$ ), while for low-income counties it was 0.028 ( $p < 0.001$ ). This indicates that counties with stronger economic foundations, due to more developed supporting infrastructure and greater capacity to absorb factors, exhibit a more pronounced digital technology empowerment effect.

Population Size: The DID coefficient for large-scale counties was 0.033 ( $p < 0.001$ ), while that for small-scale counties was 0.023 ( $p < 0.05$ ). This reflects how population size generates market demand and economies of scale, thereby amplifying the industrial driving force of digital technologies.

#### 4.2.2 Dynamic Effect Analysis

Multi-period DID results indicate: Prior to policy implementation (2018, T-1), the DID coefficient was 0.009 ( $p=0.445$ ), non-significant, validating the parallel trends assumption; Post-implementation (2020, T+1; 2021, T+2), coefficients were 0.032 ( $p < 0.001$ ) and 0.036 ( $p < 0.001$ ) respectively, exhibiting an increasing trend. This indicates the sustained and cumulative promotion of industrial diversity by digital technologies, closely linked to the long-term effects of technology diffusion and human capital accumulation.

## Conclusion

This study employs a PSM-DID approach to systematically evaluate the impact of digital technologies on rural industrial diversity by constructing county-level panel data. Empirical results demonstrate that digital technologies significantly promote the diversification of rural industrial structures, a conclusion that remains robust across multiple tests. Further analysis reveals pronounced regional heterogeneity in the enabling effects of digital technologies: counties with stronger economic foundations and larger populations derive greater benefits, reflecting the moderating role of regional development conditions on technological impacts. Dynamic effect analysis indicates that the promotion of industrial diversity by digital technologies exhibits both persistence and accumulation, gradually intensifying over time. These findings suggest that in advancing digital rural development, attention should be paid to regional disparities, strengthening infrastructure and talent support while avoiding one-size-fits-all policies. Concurrently, emphasis should be placed on the deep integration of digital technologies with local industrial foundations and social capital to achieve sustainable and inclusive rural industrial revitalisation. Future research may further explore the micro-mechanisms and path-dependence issues through which digital technologies influence industrial diversity.

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## Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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# A Study on the Influence of Conformity Psychology on Impulsive Purchasing Behaviour in Social Commerce Contexts

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**Abstract:** The profound development of mobile internet has given rise to the emerging business model of social e-commerce, which deeply integrates social interaction with online shopping, thereby reshaping consumers' decision-making pathways. Within this context, the conformity mentality stemming from group pressure significantly influences individual purchasing decisions, often leading to unplanned impulse purchases. This study focuses on the social e-commerce environment, aiming to explore the operational mechanisms through which different dimensions of conformity (informational conformity and normative conformity) influence impulsive purchasing behaviour. It further examines the mediating effect of perceived value and the moderating role of self-control. By constructing a theoretical model and conducting empirical tests, this research not only contributes to enriching consumer behaviour theory but also provides practical guidance for social e-commerce platforms to optimise marketing strategies and foster rational consumption.

**Keywords:** Social E-Commerce; Conformity; Impulse Buying; Perceived Value; Self-Control

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## 1. Introduction

### 1.1 Research Background and Problem Statement

In recent years, social e-commerce platforms such as Xiaohongshu, Douyin, and Kuaishou have rapidly emerged. Through content-driven recommendations, live-streamed sales, and community group-buying models, these platforms tightly intertwine social relationships with consumer behaviour. Compared to traditional e-commerce, the core characteristics of social e-commerce lie in its potent social attributes and the driving force of user-generated content (UGC). This exposes consumers' purchasing decision-making processes to complex social information environments. Individuals are highly susceptible to the influence of their social networks, fostering a tendency towards conformity – the phenomenon where personal decisions are altered to align with group behaviour or gain social acceptance. This psychological effect is amplified within the interactive, sharing, and display-oriented atmosphere of social e-commerce, frequently triggering impulse purchasing: a sudden, emotionally driven buying behaviour lacking thorough deliberation. Consequently, investigating the underlying mechanisms through which conformity influences impulse buying within the specific context of social e-commerce represents a significant research topic of both theoretical significance and practical urgency.

### 1.2 Research Significance

Theoretically, this study integrates classical conformity theory and impulse buying theory with the rapidly evolving social e-commerce context, thereby expanding and deepening our understanding of consumer behaviour patterns within new media environments. By introducing perceived value as a key mediating variable and self-control as a boundary condition, we construct and test an integrated theoretical model. This approach clarifies the causal pathway of “social stimulus – cognitive evaluation – behavioural response,” enhancing the explanatory power of the theory. Practical Significance The findings offer insights for social e-commerce platforms and merchants in precision marketing, such as effectively leveraging informational conformity (e.g., authentic reviews) and normative conformity (e.g., group pressure) to stimulate purchase intent. Simultaneously, it prompts platforms to prioritise consumer wellbeing by employing interface design or prompt mechanisms to assist highly impulsive consumers in self-regulation, thereby fostering a healthy and sustainable consumption ecosystem.

## **2.Literature Review**

### **2.1 The Essence and Characteristics of Social Commerce**

Social e-commerce denotes a business model that leverages social media platforms to facilitate the sale of goods or services through user social interactions (e.g., sharing, commenting, liking), content creation (e.g., short videos, illustrated notes), and community management. Its defining characteristics include: firstly, being relationship-driven, where transactions are embedded within users' trust networks, with recommendations from acquaintances or KOL (Key Opinion Leader) influence proving pivotal; secondly, content serving as the product itself, where vivid, engaging content showcases product value to spark user interest and purchasing desire; thirdly, high interactivity and immediacy, such as live-stream Q&A sessions and flash sale atmospheres creating intense immediacy and urgency; fourthly, pronounced community effects, where groups formed around shared interests or identities generate potent collective identification and peer pressure, significantly influencing members' consumption behaviour <sup>[3]</sup>.

### **2.2 Theoretical Foundations and Dimensions of Conformity Psychology**

Conformity refers to the phenomenon where individuals alter their attitudes or behaviours under real or perceived pressure to align with group standards. Deutsch and Gerard classically distinguished between informational conformity and normative conformity. Informational conformity arises when individuals, facing uncertainty, perceive the group as a reliable information source, seeking to make better decisions by following group choices. In social commerce, this manifests as reliance on user reviews, sales rankings, and influencer recommendations. Normative conformity, conversely, stems from an individual's desire for group acceptance and approval, or to avoid exclusion for deviating from the collective. Within social commerce, this manifests as purchasing popular items to gain social recognition or avoid being perceived as out of touch <sup>[4]</sup>. The public nature and interactivity of social commerce significantly amplify both these conformity mechanisms.

### **2.3 Concept and Influencing Factors of Impulsive Purchasing Behaviour**

Impulsive purchasing behaviour denotes sudden, spontaneous, and pleasure-driven buying decisions. Consumers typically lack detailed planning or thorough deliberation during such purchases, which are often accompanied by strong emotional responses. Influencing factors can be categorised into internal individual factors (e.g., personality traits, emotional state) and external situational factors (e.g., marketing stimuli, shopping environment). Within social commerce, external situational factors are particularly prominent. Examples include time-limited flash sales, the fervent atmosphere cultivated in live-streaming sessions, and friends' real-time purchase showcases, all of which effectively stimulate consumers' impulse buying desires. Such purchasing behaviour often delivers immediate emotional gratification, though it may also be accompanied by post-purchase regret <sup>[2]</sup>.

## **3.Theoretical Model and Research Hypotheses**

### **3.1 Theoretical Model Construction**

This study constructs its research model based on the S-O-R theory. The Stimulus (S) in the model refers to the conformity psychology induced by the social e-commerce environment, encompassing two dimensions: informational conformity and normative conformity. The Organism (O) denotes the consumer's internal cognitive evaluation process, with perceived value serving as the core mediating variable. The Response (R) represents impulsive purchase intention. Additionally, consumers'

self-control ability is introduced as a moderating variable to examine its attenuating effect on the path from “perceived value → impulse purchase intention”. This model aims to systematically reveal the underlying cognitive pathway through which conformity influences impulse purchasing, along with the boundary conditions of individual traits.

### 3.2 Research Hypotheses

H1: Conformity in social e-commerce contexts exerts a significant positive influence on impulse purchase intention. H1a: Informational conformity exerts a significant positive influence on impulse purchase intention. H1b: Normative conformity exerts a significant positive influence on impulse purchase intention. H2: Perceived value mediates the relationship between conformity and impulse purchase intention. H2a: Informational conformity indirectly and positively influences impulsive purchase intention by enhancing perceived value. H2b: Normative conformity indirectly and positively influences impulsive purchase intention by enhancing perceived value. H3: Self-control negatively moderates the relationship between perceived value and impulsive purchase intention, such that stronger self-control weakens the promotional effect of perceived value on impulsive purchase intention.

### 3.3 Variable Definitions and Measurement

The operational definitions of this study's core variables are as follows: Conformity behaviour draws upon the scale revised by Beversley and Li Xian-guo<sup>[1]</sup> for the Chinese context, distinguishing informational and normative influences; Impulsive purchase intention employs the scale developed by Rook and Fisher<sup>[5]</sup> and widely adopted by scholars; Perceived value, tailored to the characteristics of social e-commerce, is measured using the multidimensional scale referenced from Sweeney and Soutar<sup>[6]</sup>. All scales employed a 5-point Likert scale. Data were collected via an online questionnaire platform and analysed using SPSS and AMOS software for reliability and validity assessments, correlation analyses, structural equation modelling, and Bootstrap mediation effect testing.

## 4. Empirical Analysis

### 4.1 Data Collection and Sample Description

This study distributed questionnaires via a professional online research platform to users with social e-commerce experience. A total of 435 questionnaires were retrieved. After excluding invalid responses, 401 valid questionnaires were obtained, yielding a valid response rate of 92.2%. The demographic characteristics of the sample revealed: 55.6% were female and 44.4% male; ages were predominantly concentrated between 18 and 30 years (85.3%); educational attainment predominantly at bachelor's degree level or above (71.8%); the vast majority of respondents frequently used social e-commerce platforms (88.5% at least weekly), indicating the sample possessed good representativeness. Common method bias was assessed using Harman's single-factor method. The unrotated first factor explained 26.8% of variance, below the 40% critical threshold, suggesting common method bias was not a significant concern.

### 4.2 Reliability and Validity Analysis

First, the scales underwent reliability and validity testing. Cronbach's  $\alpha$  coefficients for all variables exceeded 0.82, with composite reliability (CR) values above 0.78, indicating high internal consistency reliability. Regarding validity, confirmatory factor analysis (CFA) revealed that standardised factor loadings for each measurement item on its corresponding latent variable exceeded 0.6, with average variance extracted (AVE) exceeding 0.5 for all items. This indicates good convergent validity for the scale. Discriminant validity was assessed by comparing the square roots of AVE for each latent variable against their respective correlations with other latent variables. Results showed all AVE square roots exceeded corresponding correlation coefficients, indicating satisfactory discriminant validity. Overall model fit indices were  $\chi^2/df=2.08$ , GFI=0.90, AGFI=0.88, CFI=0.96, RMSEA=0.052. All indices met acceptable standards, indicating good model fit.

### 4.3 Hypothesis Testing and Results Analysis

Structural equation modelling (SEM) was employed to examine direct effects. Results revealed that both informational conformity ( $\beta=0.35$ ,  $p<0.001$ ) and normative conformity ( $\beta=0.29$ ,  $p<0.001$ ) exerted significant positive influences on impulsive purchase intention, supporting hypotheses H1a and H1b. The Bootstrap method (5000 samples) was employed to examine the mediating effect of perceived value. Results indicated that the indirect effect value of informational conformity on impulse purchase intention via perceived value was 0.16, with a 95% confidence interval of [0.09, 0.24]; The indirect

effect value for normative conformity was 0.13, with a 95% confidence interval of [0.07, 0.20]. Both intervals excluded zero, confirming significant mediating effects and supporting H2a and H2b. Hierarchical regression analysis was employed to examine the moderating effect, incorporating perceived value, self-control, and their interaction term into the regression equation. The interaction coefficient was negative and significant ( $\beta = -0.09$ ,  $p < 0.05$ ), indicating that self-control mitigates the positive influence of perceived value on impulsive purchase intention. Thus, H3 is supported.

## 5. Conclusion

This study confirms that in social e-commerce contexts, conformity (whether driven by information acquisition or normative compliance) serves as a key antecedent to consumers' impulsive purchasing behaviour. Perceived value plays a crucial mediating role in this process, meaning conformity primarily catalyses impulsive purchasing decisions by enhancing consumers' perception of multifaceted product values, including emotional experience and social recognition. Concurrently, consumers' self-control capacity effectively buffers the driving effect of perceived value on purchase impulses, indicating that individuals' intrinsic regulatory abilities constitute important boundary conditions influencing behavioural outcomes. These findings reveal the intrinsic mechanism of "social influence  $\rightarrow$  value cognition  $\rightarrow$  behavioural impulse" within social e-commerce.

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## Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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# Research on the Development Pathways of the Exhibition Economy from an Urban Branding Perspective

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**Abstract:** This paper systematically explores development pathways for the exhibition economy from the perspective of city branding theory. The research indicates a strategic symbiotic relationship between city branding and the exhibition economy, characterised by “brand empowerment of exhibitions and reciprocal reinforcement of the brand by exhibitions”. Currently, China still faces challenges in this field, including insufficient strategic coordination, homogenisation of development models, short-term brand effects, and inadequate international operational capabilities. To address this, the study proposes constructing development pathways across three dimensions: strategic coordination, business model integration, and support optimisation. This involves guiding convention and exhibition industry planning with the core values of the city brand, promoting “convention and exhibition plus” industrial integration, and enhancing hardware, software, policy, and service support systems. Ultimately, this aims to achieve a virtuous cycle of interaction and coordinated development between the convention and exhibition economy and city brand building.

**Keywords:** City Branding; Exhibition Economy; Strategic Coordination; Business Model Integration; Development Pathway

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## 1.Introduction

### 1.1 Research Background and Significance

Presently, global urban competition has shifted from mere economic scale rivalry to soft power contests centred on brand image. Urban branding has become a critical strategic asset for attracting high-end resources and enhancing comprehensive competitiveness. As a vital component of modern service industries, the exhibition economy plays an irreplaceable role in shaping and disseminating urban brands through its potent resource aggregation effects, industrial driving capacity, and image dissemination functions<sup>[1]</sup>. However, common practical issues such as disconnects between exhibition activities and core city brand values, alongside imbalances between short-term gains and long-term brand development, constrain the full realisation of synergistic effects. Therefore, systematically examining and planning exhibition economy development pathways from a strategic city branding perspective not only enriches the theoretical frameworks of both city branding and exhibition economics but also holds significant practical implications for advancing urban economic restructuring and achieving sustainable development. This study aims to construct a theoretical framework that deeply integrates city brand development with the exhibition economy, providing differentiated and actionable practical guidance for cities with varying endowments<sup>[2]</sup>.

### 1.2 Review of Domestic and International Research

Domestic research on the exhibition economy and city branding exhibits a developmental trajectory from fragmented to

integrated approaches, and from descriptive analysis to mechanistic exploration. Early studies predominantly focused on evaluating the economic benefits of exhibitions or constructing single-dimensional city brands. Over the past decade, scholars have increasingly turned their attention to the intersection of these two fields, such as examining the instantaneous enhancement of a city's international image through major exhibition events (e.g., the Olympics, World Expos), or analysing the value of the exhibition industry as a city marketing tool<sup>[3]</sup>. Nevertheless, most studies remain confined to case analyses or strategic recommendations, lacking in-depth exploration of how city brand strategies can systematically guide the long-term development planning of the exhibition industry. The modelling and theoretical construction of the intrinsic mechanisms governing their interaction remain relatively underdeveloped. Overseas research commenced earlier, grounded in established theories such as destination marketing, event management, and urban regeneration. It places greater emphasis on quantifying the long-term impact of major events on urban brand equity (including awareness, reputation, and loyalty), while also addressing socio-cultural dimensions like community engagement and sustainability. Overall, existing research offers valuable insights for this paper; nevertheless, substantial scope remains for further exploration in constructing an integrated theoretical and practical framework applicable to China's urbanisation context<sup>[4]</sup>.

## **2.Theoretical Framework and Interaction Mechanisms of City Branding and the Exhibition Economy**

### **2.1 Core Essence and Constituent System of City Branding**

A city brand constitutes the holistic, generalised perception and associations formed in the public consciousness regarding a specific city, comprehensively reflecting its unique geographical, economic, cultural, and social elements. It represents a significant strategic intangible asset. Its composition forms a complex, multi-layered, and multi-dimensional system, which can be deconstructed into three core levels: The core layer comprises the city spirit and brand positioning—the city's unique value proposition, developmental vision, and cultural core—which determine the brand's distinctiveness and directionality; The intermediate layer comprises the city's behavioural identification system, encompassing governmental governance efficacy, corporate conduct standards, civic cultural literacy, and the quality and distinctiveness of economic and cultural activities. This layer embodies the practical fulfilment of brand commitments. The surface layer constitutes the city's visual and sensory identification system, including urban landscapes, landmark architecture, public art, environmental quality, and visual symbols such as logos and slogans. This layer serves as the most immediate vehicle for brand communication. The combined effect of these three layers forms the public's holistic perception of the city brand<sup>[5]</sup>.

### **2.2 The Multifaceted Value and Functional Positioning of the Exhibition Economy**

The exhibition economy constitutes a comprehensive economic model centred on conferences, exhibitions, incentive travel, and festival events. Through its potent platform effect, it drives the development of related industries. Its value extends far beyond direct venue rentals and participant expenditure, manifesting in multidimensional functional contributions. Economically, it possesses a significant multiplier effect, powerfully stimulating downstream sectors such as accommodation, catering, transport, advertising, and logistics. Industrially, it serves as an efficient platform for technological exchange, product launches, and trade matching, fostering industrial upgrading and innovation diffusion. Socioculturally, large-scale events enhance community cohesion and enrich citizens' cultural lives. At the city branding level, its core functions lie in the "focus amplification effect" and the "experience shaping effect". Through meticulously planned events, it concentrates global or regional attention on the city within a short timeframe, while providing participants with direct, immersive experiences of the city's image, efficiency, services, and culture. This makes it the most vivid and powerful medium for communicating the city's brand.

### **2.3 The Internal Logic and Functional Model of Their Interactive Integration**

City branding and the exhibition economy form a symbiotic relationship of "value-cycle reinforcement". City branding acts as a "gravitational field" and "navigator", attracting high-quality exhibition projects through clear positioning while guiding differentiated industrial development. Conversely, exhibition events function as "accelerators" and "touchstones", conveying brand value through concentrated exposure and experiential engagement. This compels cities to enhance infrastructure and management standards, thereby testing brand commitments. This creates a virtuous cycle where "brand empowers

exhibitions, and exhibitions nourish brand,” forming the core mechanism driving the synergistic advancement of soft power and economic growth.

### **3. Current Status and Challenges in China’s Urban Exhibition Economy and Brand Development**

#### **3.1 Major Achievements and Development Characteristics**

After decades of development, China’s exhibition economy has risen to global prominence. Beijing, Shanghai, Guangzhou, and Shenzhen leverage their comprehensive strengths to host numerous international events, establishing themselves as major global exhibition cities. Meanwhile, locations such as Hangzhou and Boao have pursued differentiated paths by capitalising on distinctive resources, effectively enhancing their international recognition. The industry currently exhibits four key characteristics: deepening marketisation, with professional exhibition companies becoming the mainstay; pronounced trends towards specialisation and branding, giving rise to a cohort of industry-leading brand exhibitions; accelerated technological integration, with smart and green exhibitions becoming mainstream; and optimised regional distribution, expanding from the eastern coastal regions to central and western areas, revealing a trend towards coordinated development.

#### **3.2 Principal Challenges and Underlying Contradictions**

China’s exhibition economy and brand development still face multiple challenges in achieving synergistic progress: Firstly, a disconnect exists at the strategic level, with urban planning and brand strategies failing to effectively align with the exhibition industry, resulting in mismatched exhibition themes and city positioning. Secondly, development models exhibit pronounced homogenisation and extensive growth, characterised by a blind pursuit of exhibition centre scale and quantity while neglecting unique characteristics, leading to resource wastage. Thirdly, brand effects remain short-term, prioritising exposure during events over long-term cultivation, hindering the establishment of sustained influence. Fourthly, international operational standards remain inadequate, with gaps persisting compared to leading global cities in terms of branded exhibition numbers, rule-setting influence, and professional services. Utilisation rates at some venues are low, exposing the risk of “having venues but no events”.

#### **3.3 In-depth Analysis of Root Causes**

These issues stem from multifaceted complexities: institutionally, compartmentalised management leads to fragmented policies and inefficient coordination; developmentally, excessive reliance on government initiatives undermines market mechanisms and societal engagement; resource-wise, there is a severe shortage of high-calibre, multidisciplinary professionals; and evaluation-wise, performance metrics prioritise short-term hardware indicators over scientific assessment of long-term benefits like brand value and knowledge spillovers, thereby incentivising short-termism.

### **4. Developing Pathways for the Exhibition Economy Under City Brand Leadership**

#### **4.1 Strategic Synergy Pathway: Guiding Convention and Exhibition Industry Planning with Brand Core Values**

Cities must elevate the development of the exhibition economy to the core level of their city brand strategy, achieving a fundamental shift from “hosting events for the sake of hosting events” to “hosting events for the sake of the brand”. The primary task is to conduct scientific and precise city brand positioning and auditing, clearly defining the city’s Unique Selling Proposition (USP) and core value proposition. Building upon this foundation, an integrated top-level design for both MICE sector development and city branding must be formulated. This ensures every major MICE event—whether introduced, nurtured, or created—closely aligns with and serves the city brand’s overarching strategy. For instance: while a city branded as a “historical and cultural metropolis” should concentrate on developing conferences and exhibitions related to cultural creativity, heritage preservation, and tourism. Concurrently, a permanent interdepartmental coordination mechanism should be established, led by municipal leadership and encompassing commerce, publicity, culture and tourism, planning, and foreign affairs departments. This mechanism must break down departmental silos, forge policy synergy, and ensure the effective implementation of strategic objectives.

#### **4.2 Pathways for Industry Integration: Forging a Differentiated, Experiential Brand Exhibition System**

Promote deep integration between the exhibition economy and the city's leading industries, distinctive resources, and cultural life to construct an "exhibition+" ecosystem. Firstly, implement the "exhibition+leading industries" strategy. Focusing on the city's pillar industries and strategic emerging sectors, cultivate a portfolio of globally influential specialised brand exhibitions. This will position exhibitions as barometers and catalysts for industrial development, thereby reinforcing the city's economic brand image. Secondly, advance the integration of "exhibition + cultural tourism" by developing locally distinctive festivals, sporting events, and performing arts activities. Seamlessly combine exhibition venues and major events with city tourism routes and cultural experience products to extend visitor stays, boost overall consumption, and vividly showcase the city's cultural appeal. Thirdly, develop "exhibition + digital economy" by actively employing digital technologies such as big data, cloud computing, and VR/AR to create new smart exhibition models integrating online and offline experiences. This approach overcomes physical space limitations, enhances participant engagement, and simultaneously shapes the city's image as an innovative and intelligent frontier. Through such sector integration, a distinctive exhibition brand cluster highly aligned with the city's brand characteristics and difficult to replicate will ultimately emerge.

### **4.3 Supporting Optimisation Pathways: Establishing an Internationalised, Professional Sustainable Development Environment**

A robust support system is fundamental to the sustained, healthy development of the exhibition economy and its effective empowerment of city branding. Regarding hardware support, scientific planning of exhibition facility layouts is essential, prioritising the practicality and flexibility of venue functions alongside synergistic integration with surrounding transport, hotel, and commercial infrastructure, avoiding blind pursuit of scale or foreign trends. Software support constitutes the core competitiveness. Efforts should focus on cultivating a cohort of internationally competitive local exhibition industry leaders, while vigorously attracting and nurturing a high-calibre professional workforce proficient in international protocols, project management, and brand marketing. Policy support requires refining targeted assistance measures concerning land use, financing, taxation, and talent acquisition, thereby fostering a stable, equitable, transparent, and predictable business environment. Service support requires comprehensively enhancing the city's international service standards, including streamlining visa procedures, providing multilingual information services, establishing a high-calibre volunteer corps, and ensuring urban environmental and public health safety. By delivering an exceptional attendee experience, every participant should become an active ambassador for the city's brand. Furthermore, significant emphasis must be placed on the green, low-carbon, and sustainable operation of exhibition activities, positioning this as a key manifestation of the city's responsible brand image.

## **Conclusion**

This study systematically demonstrates the strategic, symbiotic interaction between city branding and the exhibition economy. It identifies core challenges currently faced by Chinese cities in this domain: insufficient strategic coordination, extensive development models, transient brand effects, and inadequate support systems. The fundamental solution lies in transforming the development paradigm—shifting from isolated, fragmented exhibition economy development towards a systematic, integrated approach guided by the city's core brand values. This involves advancing exhibition industry planning, business model innovation, and environmental development. Successful implementation relies on effective collaboration among diverse stakeholders—including government, enterprises, industry organisations, and communities—alongside sustained investment and brand maintenance grounded in a long-term perspective. The study's three-dimensional pathway model—strategy-business format-support—provides urban administrators with an integrated action framework.

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# Innovative Market Research for Identifying Untapped Consumer Segments in China's E-commerce Market

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**Abstract:** The rapid advancement of modern information technology has propelled the swift emergence and maturation of e-commerce. This phenomenon has not only transformed traditional business models but also provided contemporary consumers with more convenient shopping options. Against this backdrop, consumer purchasing behaviour has undergone significant shifts, leading to an increasingly segmented e-commerce market where numerous unidentified and untapped consumer groups persist. This paper briefly analyses the e-commerce market and the concept of untapped consumer groups, summarises the characteristics of such groups within China's e-commerce landscape, and outlines the principles for identifying innovative markets among these untapped consumers. Ultimately, it proposes corresponding strategies to promote the sustainable development of the e-commerce market, aiming to provide reference for professionals.

**Keywords:** Chinese E-Commerce Market; Untapped Consumers; Innovative Markets; Identification Methods

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## Introduction

E-commerce, a product of the information technology era, has evolved at a rapid pace, continuously driving transformations in global business models. China's e-commerce market is currently transitioning from high-speed growth towards high-quality, sustainable development<sup>[1]</sup>. By leveraging technological innovation to unlock domestic market potential, in-depth research into identifying untapped consumer segments within China's e-commerce market can assist enterprises in formulating more precise marketing strategies, maintaining market order, and fostering harmonious socio-economic development<sup>[2]</sup>. To this end, diversified approaches should be adopted in practice to identify innovative markets for untapped consumer groups<sup>[3]</sup>.

## 1.The E-commerce Market and the Essence of Untapped Consumer Segments

### 1.1 The E-commerce Market

The e-commerce market specifically refers to an online transactional ecosystem utilising the internet as its medium, employing modern digital technologies to facilitate the exchange of goods, services, and information. It transcends the temporal and spatial constraints of traditional markets, precisely connecting buyers and sellers across numerous models including business-to-business (B2B), business-to-consumer (B2C), and consumer-to-consumer (C2C). Its core lies in applying network technologies to optimise supply-demand matching and reduce transaction costs, constituting a central form



of modern commercial activity <sup>[1]</sup>. The characteristics of the e-commerce market manifest in three principal aspects. Firstly, e-commerce overcomes the temporal and spatial constraints of traditional commerce, enabling consumer groups to purchase and browse goods via the internet at any time and location. Secondly, the e-commerce market encompasses vast quantities of product information, allowing consumers to compare prices and performance to make optimal decisions. Thirdly, the modern technologies derived within the e-commerce market can precisely align with consumers' individualised demands, significantly streamlining transaction processes.

## **1.2 Untapped Consumer Segments**

Untapped consumer segments within the e-commerce market primarily refer to potential user groups that remain inactive and unreachable by existing e-commerce models due to behavioural habits, demographics, and numerous other factors. These consumer groups are substantial in scale but remain underdeveloped owing to inadequate adaptability. They can be activated through various means, including simplified interactions and optimised infrastructure.

## **2.Characteristics of Untapped Consumer Segments in China's E-commerce Market**

### **2.1 Concentrated Distribution with Inadequate Device Infrastructure**

Underserved consumer groups in China's e-commerce market exhibit concentrated distribution yet inadequate device provision. On one hand, these groups are predominantly located in rural areas or lower-tier cities, characterised by relatively remote geographical positions and low network coverage density. Even after purchase, delivery times remain lengthy, creating an impasse in the "last mile" of online transactions. Conversely, these regions lack convenient access to modern tools like mobile payments and digital authentication. Some consumers, hindered by unstable network environments and limited digital literacy, struggle to complete online transactions. These characteristics prevent standard e-commerce models from effectively replicating services or precisely targeting this demographic.

### **2.2 Significant Variations in Age and Skill Levels**

The underserved consumer demographic exhibits considerable variation in age and skill levels, encompassing middle-aged and elderly individuals, low-income groups, students, and homemakers. Middle-aged and elderly individuals possess limited proficiency with modern smart devices, struggle with complex interactive interfaces, and exhibit consumer apprehension. Low-income groups face constraints in device capabilities and online spending, resulting in insufficient browsing and transaction time. Whilst students and homemakers demonstrate some digital engagement, their overall consumption decisions are heavily influenced by practical constraints, leading to distinct priorities in their demand for e-commerce services.

### **2.3 Preference for Value for Money and Practicality**

The preference for value for money and practicality among untapped consumer groups manifests in two primary ways. Firstly, these groups exhibit significantly higher price sensitivity than pursuit of personalisation, tending to select products that fulfil basic needs with clear functionality. They demonstrate greater enthusiasm for discount promotions and preferential policies. Secondly, when choosing goods, such groups typically prioritise ease of use, durability, and product compatibility.

### **2.4 Unfamiliarity and Distrust Towards Transactions**

This segment frequently exhibits unfamiliarity and distrust towards transactions. Firstly, they are often unfamiliar with online transaction processes, unclear about how to search for products or handle returns and exchanges, and may experience frustration during the process. Secondly, some express concerns about the security of online transactions, including risks of user information leakage and products not matching descriptions. This characteristic directly impedes the effectiveness of standard e-commerce traffic conversion strategies.

## **3.Principles for Identifying Untapped Consumer Segments in China's E-commerce Market Innovation**

### **3.1 Demand-Oriented Principle**

The foremost principle in identifying untapped consumer segments within China's e-commerce market is demand orientation. The identification process must prioritise addressing the disconnect between existing e-commerce offerings and the needs of these untapped groups. This involves comprehensively gathering behavioural data from untapped consumers to uncover gaps

arising from contextual limitations or capability constraints. This ensures identification efforts precisely align with the actual requirements of these segments, avoiding the pitfall of prioritising coverage over fundamental needs. This approach lays the groundwork for subsequent marketing strategies.

### 3.2 Precise Segmentation Principle

The precision segmentation principle addresses the disparate needs within untapped consumer groups. Rather than treating them as a homogeneous entity, identification requires dividing them into distinct tiers based on actual circumstances. This prevents resource misallocation stemming from broad categorisation or one-size-fits-all approaches. Examples include segmenting unidentified consumer groups by age or income level.

### 3.3 Feasibility Principle

The Feasibility Principle requires that while data mining identifies potential consumer groups, the assessment must also evaluate whether existing technology and costs can support these untapped consumers' participation in consumption. If a group's needs cannot be reached by technology or if multiple constraints prevent their participation in consumption, such groups should be excluded from the scope of untapped consumer identification.

## 4. Innovative Market Strategies for Identifying Untapped Consumer Segments in China's E-commerce Market

### 4.1 Implementing Multi-Data Fusion Approach for Identification

Multi-data fusion aims to combine three data sources to identify untapped consumer groups due to mismatched capability requirements or contextual scenarios, as shown in Table 1.

*Table 1: Data Categories and Specific Contents for Identification*

Data Category	Specific Content
In-platform behavioural data	Group browsing trajectories, dwell time, search keywords
External Environmental Data	Per capita disposable income, digital infrastructure indicators, consumption expenditure structure
Attribute Data	Age, device performance tiering

The three primary data categories encompass: analysing behavioural data from untapped consumer segments within the platform, covering browsing paths, search keywords, dwell time, etc., to precisely capture consumer interest inclinations and actual needs. Collecting external environmental data, including regional digital infrastructure metrics, per capita disposable income, and consumption expenditure structure, to assess accessibility challenges and environmental constraints <sup>[2]</sup>. Collecting attribute data on untapped consumer groups—such as age and device performance tiering—enables precise characterisation of their engagement capabilities. Subsequently, after gathering extensive data, construct a model based on “demand intensity, initial difficulty, and conversion potential”. Finally, synthesise analyses to define diverse group profiles—including demand perspectives and development priorities—providing a foundation for subsequent strategy formulation and ensuring more comprehensive identification.

### 4.2 Scenario-Based Demand Exploration and Untapped Market Positioning

By systematically mining actual user needs across diverse scenarios originating from the real-life contexts of untapped consumer groups, effective identification can be achieved. Firstly, conduct scenario collection and classification, employing modern language processing techniques to perform sentiment analysis on texts such as user reviews and customer service dialogues within e-commerce platforms, extracting high-frequency demand keywords and specific contexts. Secondly, transform scenarios into service and product requirement elements. For instance, in emergency procurement scenarios, users prioritise reliability and timeliness, while festive gifting scenarios emphasise convenience and cultural appropriateness. This approach avoids identifying untapped consumer groups based solely on product categories. Instead, it uncovers structural gaps through demand discovery, pinpointing entry points and providing clear direction for precise identification.

### 4.3 Implementing Low-Threshold Design and Inclusive Experiences

Implementing low-barrier design and inclusive experiences aims to reduce market entry barriers for untapped consumer

groups, lowering operational and cognitive difficulties to facilitate seamless access to e-commerce. Firstly, optimise visual presentation on e-commerce platforms by employing large font sizes, high-contrast colour schemes, combined with simplified icons and linear layouts to enhance usability for these groups. Secondly, streamline user engagement processes by converting search, order placement, and payment interfaces into one-click access and default options. Thirdly, enhance network configurations in remote areas, prioritising front-end resource loading optimisation to ensure e-commerce platforms function reliably on low-performance devices and unstable networks<sup>[3]</sup>. Finally, establish trust and security through design by incorporating straightforward prompts and verifiable security badges within service windows. Implementing these multifaceted approaches will ensure untapped consumer groups can promptly engage with the e-commerce market.

#### **4.4 Leveraging Ecological Synergy and Regional Supply Adaptation**

Leveraging ecosystem collaboration and regional supply adaptation aims to integrate regional services, logistics, and other ecosystem entities. This approach supports networks tailored to the capabilities and geographical characteristics of untapped consumer groups, addressing participation barriers caused by insufficient supply or inadequate infrastructure. On one hand, establishing regional logistics hubs or village/community collection points in underdeveloped areas shortens the “last mile”. Simultaneously, deliveries are optimised based on the consumption patterns of untapped consumer groups, enhancing delivery reliability and timeliness. Concurrently, regional supply chains are consolidated by selecting merchants with operational capacity within the area. This reduces reliance on cross-regional and long-distance logistics, thereby enhancing trust among untapped consumer groups. Through this approach, untapped consumers develop online transaction habits while enjoying convenient and trustworthy experiences, enabling precise identification.

### **Conclusion**

In summary, untapped consumer segments within China’s e-commerce market exhibit concentrated distribution yet inadequate device access, significant age and skill disparities, a preference for value-for-money and practicality, alongside unfamiliarity and distrust towards transactions. Practical strategies should be grounded in these characteristics, employing multiple approaches including: implementing multi-data fusion for identification; exploring scenario-based needs and identifying untapped market segments; developing low-barrier designs and inclusive experiences; and leveraging ecosystem collaboration with regional supply adaptation. These measures will foster the healthy and sustainable development of the e-commerce market.

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# **Harnessing Globalization: Reducing Inequality and Fostering Growth**

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**Abstract:** This article employs modernization theory and global value chain (GVC) theory to examine globalization's positive role in reducing inequality and fostering economic development. The analysis reveals that through economic integration, technology transfer, and participation in global production networks, globalization significantly catalyzes growth and poverty reduction. Illustrative cases include South Korea and Singapore's economic transformation via export-oriented policies; China's Guangdong-Hong Kong-Macao Greater Bay Area attracting foreign investment and technology through special economic zones, with platforms like the China-Singapore Guangzhou Knowledge City accelerating industrial upgrading; and India's IT services sector creating over 17 million high-wage jobs by leveraging its skilled labor force. However, these benefits are not automatic, but rather highly contingent upon national strategic policies, institutional governance capacity, and socioeconomic infrastructure investment. The study underscores that only countries with effective governance and forward-looking development strategies can fully harness globalization's potential to achieve inclusive growth.

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## **1.Introduction**

Globalization, characterized by the increasing interconnectedness and interdependence of the world's economies, societies, and cultures, has profoundly reshaped the global political economy over the past few decades. This phenomenon has facilitated unprecedented levels of trade, investment, technology transfer, and movement of people across borders, creating new opportunities and challenges for countries around the world. While critics argue that globalization exacerbates disparities, this essay will focus on exploring the positive impacts of globalization on reducing inequality and fostering economic development.

However, it is crucial to critically evaluate whether these positive impacts are universally experienced or if they disproportionately benefit certain regions and populations. The narrative of globalization as a force for good often overlooks the complexities and varying outcomes it produces. Therefore, this essay will not only highlight the beneficial effects of globalization but also scrutinize the contexts and conditions under which these benefits are realized.

This essay aims to demonstrate how globalization, through mechanisms such as economic integration, technology transfer, and participation in global production networks, can contribute to reducing inequality and promoting inclusive growth. By examining these mechanisms, the essay will highlight the ways in which globalization has enabled many developing countries

to achieve significant economic advancements, thereby improving living standards and reducing poverty. The analysis will be framed through the lenses of modernization theory and global value chains (GVC) theory, which provide insightful explanations for the beneficial effects of globalization.

The essay will first establish the theoretical frameworks and definitions essential for understanding the positive impacts of globalization on inequality. It will then delve into the specific positive impacts, examining how increased economic integration and participation in global production networks have spurred growth and development in various regions. Finally, the essay will discuss the contexts and conditions under which these benefits are realized, providing a balanced and comprehensive understanding of how globalization can act as a powerful force for reducing inequality and fostering economic prosperity.

## **2.Theoretical Framework and Definitions**

To analyze the positive impacts of globalization on inequality in the global political economy, it is essential to first establish a theoretical framework and clarify key definitions. This section provides an overview of globalization, inequality, and the theories that will be discussed in detail in subsequent sections.

### **2.1 Globalization and Inequality**

Globalization refers to the process of increasing interconnectedness and interdependence among countries through economic, social, cultural, and political exchanges. This phenomenon is driven by advances in technology, communication, and transportation, facilitating the flow of goods, services, capital, people, and information across borders. Globalization has been a significant force shaping the global political economy, influencing economic policies, trade practices, and social structures. Inequality encompasses disparities in income, wealth, and opportunities among individuals and groups within and between countries. It can be measured in various ways, including Income Inequality (Differences in income distribution within a population), Wealth Inequality (Disparities in the distribution of assets and wealth), Opportunity Inequality (Unequal access to education, healthcare, and employment opportunities). Understanding these dimensions of inequality is crucial for analyzing the impacts of globalization.

### **2.2 Overview of Theories**

To provide a structured analysis of the positive impacts of globalization on inequality, we will utilize two key theories: modernization theory and global value chains (GVC) theory. Modernization theory posits that globalization promotes economic development and modernization in developing countries. According to this theory, as countries integrate into the global economy, they adopt modern practices, technologies and institutions, leading to economic growth and social progress. Key proponents of modernization theory argue that globalization facilitates a linear progression from traditional to modern stages of development, reducing poverty and improving living standards. Global value chains (GVC) theory<sup>[1]</sup> examines how production processes are fragmented and distributed across different countries. This theory highlights how different stages of production are located where they can be carried out most efficiently, leading to economic integration and development in participating countries. GVC theory emphasizes the role of global production networks in enhancing productivity, creating jobs, and fostering economic diversification.

These theories provide the foundation for our analysis of the positive impacts of globalization on inequality. By examining the mechanisms through which globalization influences economic development and reduces disparities, we can gain a comprehensive understanding of its beneficial effects.

## **3.Positive Impacts of Globalization on Inequality Using Theories**

In this section, we will explore the positive impacts of globalization on inequality, focusing on how increased economic integration and participation in global production networks have spurred growth and development in certain regions. This analysis will utilize modernization theory and global value chains (GVC) theory to highlight the beneficial effects of globalization.

Modernization theory suggests that globalization promotes economic development and modernization in developing countries. Modernization theory is a socio-economic theory that explains the process of transition from a traditional or



underdeveloped society to a modern society. According to this theory, as countries integrate into the global economy, they adopt modern practices, technologies, and institutions, leading to economic growth and social progress. The theory posits that the integration of developing countries into the global economy can facilitate economic growth and modernization through several mechanisms: economic integration, transfer of technology and knowledge, investment in infrastructure, access to capital and cultural exchange. Here, we examine the positive impacts of globalization through the lens of modernization theory.<sup>[2]</sup>

### 3.1 Economic Growth and Poverty Reduction

Globalization has contributed to significant economic growth in many developing countries, reducing poverty and improving living standards. Modernization theory posits that economic development follows a linear progression from traditional to modern stages. Globalization acts as a catalyst by providing access to advanced technologies, management practices, access to market and investment. For example, South Korea experienced rapid industrialization and economic growth due to its integration into the global economy. The Republic of Korea has achieved remarkable success in recent decades in combining rapid economic growth with significant poverty reduction, with real gross domestic product (GDP) growing on average by 5.7% annually between 1980 and 2023.<sup>[3]</sup> According to the World Bank, since Korea's accession to the OECD in 1996, its economy has gradually shifted to an export-oriented model, with exports of goods and services as well as merchandise rising. Korea's total exports of goods and services amounted to \$154.9 billion in 1996 and reached \$813.8 billion in 2022. During this period, merchandise exports increased from \$129.7 billion in 1996 to \$683.6 billion in 2022, while services exports grew from \$25.2 billion to \$130.2 billion, resulting in the total export volume more than quintupling in size. Meanwhile, its export trade as a share of GDP has been expanding after shifting to an export-oriented economy, reaching a staggering 54.1% in 2012, and despite the impact of the epidemic on global export trade, Korea's export trade has recovered very quickly, reaching 48.3% in 2022, with a trend of continued growth. By adopting export-oriented policies, South Korea transformed from a low-income agrarian society to a high-income industrial powerhouse. Korea's gross national income (GNI) per capita increased rapidly from US\$67 in the early 1950s to US\$33,745 in 2023.<sup>[4]</sup>

Similarly, Singapore leveraged globalization to become one of the world's most advanced economies. By creating a favorable environment for foreign direct investment (FDI) and emphasizing trade, Singapore achieved substantial economic growth and poverty reduction. In the 1960s, the city-state of Singapore was an undeveloped country with a GDP per capita of less than U.S. \$320. Today, it is one of the world's fastest-growing economies. Its GDP per capita has risen to an incredible U.S. \$60,000, making it one of the strongest economies in the world. As a small country with few natural resources, Singapore's economic leap forward has been remarkable. By embracing globalization, free-market capitalism and pragmatic policies, Singapore has overcome its geographical disadvantages to achieve significant economic success and improve its economic position. According to the United Nations Conference on Trade and Development's World Investment Report 2023, FDI inflows to Singapore reached a record \$141.2 billion in 2022, up from \$131.1 billion a year earlier (+7.7%), making the country the world's third-largest recipient of FDI after the U.S. and China, and accounting for nearly two-thirds of FDI inflows to ASEAN countries.<sup>[5]</sup> Since independence, Singapore has been working to improve the country's business environment to attract foreign investment, including measures to strengthen infrastructure, introduce investor protection legislation, set lower tax rates, foster a peaceful environment and reduce corruption. According to the latest data, Singapore is ranked 19th on the AT Kearney Foreign Direct Investment Confidence Index 2023 on the most attractive economies for foreign investment. It also ranks 1st out of 184 on the 2023 Index of Economic Freedom. The positive effects of embracing globalization on a country's economic development and improving international inequality can thus be seen.<sup>[6]</sup>

Modernization theory explains these successes by highlighting the adoption of modern technologies, practices, and policies that have spurred economic growth. The theory suggests that globalization facilitates the transfer of knowledge, technology, and capital, enabling developing countries to modernize and improve their economic conditions. These countries have effectively harnessed globalization to transition from traditional economies to modern industrialized states, reducing poverty and inequality in the process.

### 3.2 Technology and Skills Transfer



Globalization facilitates the transfer of technology and skills, promoting development and reducing inequality. Modernization theory emphasizes the importance of technology and skills transfer in the development process. Globalization facilitates this transfer through foreign direct investment, international trade, and global communication networks.

China's rapid growth is evidence of above. China's rapid economic growth is partly attributed to its openness to FDI and technology transfer. The establishment of special economic zones (SEZs) in the late 20th century attracted foreign firms, which brought advanced technologies and management practices. This influx of technology and knowledge significantly boosted China's industrial capabilities and productivity.<sup>[7]</sup> China introduced its SEZs as a part of economic reforms in the end of the 1970s. After that, they have been described as the engines of China's regional economy. A distinctive feature of the SEZ program is its decentralized implementation. An administrative committee, commonly selected by the local government, oversees the economic and social management of the zone, including approving the FDI projects up to a certain limit, building and improving the infrastructure, and regulating the land use on behalf of the local administration. The main directions and objectives of China's SEZs are: to build SEZs by attracting and utilizing foreign investment; to develop mainly Chinese-foreign joint ventures, partnerships and wholly foreign-owned enterprises; to develop export-oriented products; and to develop economic activities driven by market forces. Some studies have pointed out that the SEZ program has an overall positive effect on investment. SEZs offered an attractive policy package for foreign investors, including private property rights protection, tax incentives, and favorable land use policies. These measures made SEZs highly appealing to foreign investors. Supported by these incentives, the municipal government approved the establishment of special economic zones, which allowed them to attract significantly more foreign direct investment (FDI). Under the SEZ program, the per capita level of FDI increased by an average of 21.7%, which is an increase of 6.9 percentage points. On the other hand, SEZs were strategically designed to attract technologically advanced industrial facilities. The policies and infrastructure in these zones were geared towards promoting high-tech industries and export-oriented manufacturing. Foreign investment and the presence of firms bring with them advanced technologies, which are to some extent passed on to local firms. Such technology transfer is a key factor in increasing local productivity and innovation.<sup>[8]</sup>

In the case of the Greater Bay Area of China, for example, this new special economic zone of China exemplifies the positive role of special economic zones in attracting foreign direct investment and enabling technology transfer in the context of globalization. According to the 'Outline Development Plan for the Guangdong-Hong Kong-Macao Greater Bay Area', the Greater Bay Area has introduced a series of policies to attract foreign investment, promote innovation, protect intellectual property rights and financial integration.<sup>[9]</sup> The Greater Bay Area has witnessed a significant increase in foreign direct investment (FDI) inflows and technology imports, primarily driven by those policies. According to the Ministry of Commerce of the People's Republic of China (2021), FDI inflows into the GBA reached USD 139.2 billion in 2020, representing a 12.3% increase from the previous year. This growth can be attributed to the enhanced connectivity and cooperation fostered by the globalization, which has attracted foreign investors and technology providers to the region. Moreover, the GBA has seen a surge in technology imports as companies seek to acquire advanced technologies and know-how abroad. Data from the General Administration of Customs of the People's Republic of China (2021) reveals that the value of technology imports in the GBA reached USD 58.6 billion in 2020, a 15.7% increase from 2019. This trend highlights the region's commitment to leveraging international resources and expertise to drive technological innovation and industrial upgrading.<sup>[10]</sup>

The Greater Bay Area achieves technology transfer through cross-border technology transfer platforms and mechanisms, localization and adaptation of foreign technologies as well as reverse innovation and indigenous technology development. On cross-border technology transfer platforms and mechanisms, one notable example is the China-Singapore Guangzhou Knowledge City (CSGKC). This platform is a testament to the contribution of special economic zone projects to the promotion of international technology transfer and innovation, attracting high-tech companies and research institutes from both countries. It provides a platform for joint research and development, technology licensing, and commercialization of research outcomes.<sup>[11]</sup> As of 2019, the CSGKC had attracted over 1,200 enterprises, with a total investment of more than 100 billion yuan (approximately \$15.5 billion).<sup>[12]</sup> On localization and adaptation of foreign technologies, A prime example of successful Localization and adaptation of foreign technology in the GBA is the Guangzhou Automobile Group Co., Ltd. case.

GAC Group has established joint ventures with foreign automakers such as Toyota, Honda, and Mitsubishi to introduce and localize advanced automotive technologies in the Chinese market. Through these collaborations, GAC Group has successfully adapted foreign technologies to develop new vehicle models tailored to the preferences of Chinese consumers, such as the GAC Toyota iA5, an electric vehicle designed specifically for the Chinese market.<sup>[13]</sup>

As mentioned above, Modernization theory argues that such transfers are essential for development because they enable developing countries to upgrade their industries and increase productivity. This process provides better employment opportunities and higher wages, helping to reduce income inequality. Integration of advanced technology leads to greater efficiency and productivity, which boosts economic growth and raises living standards. In addition to the modernization theory, there is another theory that can demonstrate the positive impact of globalization in addressing inequality.

### 3.3 Improvement in Labor Markets

The Global Value Chain (GVC) theory examines how production processes are carried out in different countries and tries to explain the emergence of GVCs and why different countries take on different production responsibilities. The theory emphasizes how to achieve the most efficient combination of production stages and places of production, thereby promoting economic integration and development in participating countries.<sup>[14]</sup>

Participation in global value chains can lead to improvements in labor markets and working conditions. GVC theory suggests that participation in global production networks can improve labor markets by creating more jobs and increasing wages. For example, The IT and business process outsourcing sectors in India have created numerous high-skilled jobs, improving wage levels and employment conditions for a large segment of the population. The services sector is considered one of the key drivers of domestic growth and exports, with India's services sector employing nearly 31% of the country's labor force and contributing more than 50% of India's GDP. India's services exports have grown from less than \$4 billion at the beginning of the 21st century to \$25.45 billion in 2022, with a large portion coming from information technology (IT) and business process outsourcing (BPO) services, which account for more than \$157 billion by 2021 to 2022, and a significant portion of the total. 60 to \$157 billion between 2021 and 2022. The huge demand for outsourcing of IT technology and services has created many jobs and employment opportunities in India, with direct employment in IT and BPO estimated at 5.1 million and indirect employment estimated at more than 12 million in 2021-2022.<sup>[15]</sup> On top of that, jobs in the IT and BPO industries typically have higher pay scales compared to other industries. This is especially true for highly skilled positions such as software development, data analytics, and customer service management, which tend to have higher salaries due to their more technical nature.

India has demonstrated unique strengths in integrating into global value chains that give it a high comparative advantage in areas such as IT technology and service process outsourcing.<sup>[16]</sup> First, India has accumulated a lot of highly skilled labor force in the past decades of development, and India has the largest number of graduates in information technology majors, business administration majors, and philosophy majors among the outsourcing service-oriented countries in the world. This abundant supply of talent enables India to meet the growing demand for software testing, application development and other advanced IT services. Second, the cost of services in India is much lower than in developed countries. This is largely due to India's abundant labor supply and the government's policy support for operations. The availability of labor is India's demographic dividend, and as a major contributor to GDP, these service outsourcing industries also receive a lot of policy support from the government.<sup>[17]</sup> In addition, the construction of competence centers like technology parks and other areas to attract and develop talent has ensured the workforce needed for India's service sector. Third, India's BPO industry has the second largest English-speaking population in the world, with more than 125 million people, or more than 10% of the country's total population. According to surveys, Indian adults rank among the top Asian countries in English proficiency in their industry.<sup>[18]</sup> These factors contribute to India's comparative advantage in receiving outsourced services. In 2021, Indian companies are already responsible for 56% of the world's BPO workload, with nearly three-fifths of revenue coming from call center outsourcing and the rest from data entry and other IT-related services. During the same period, Indian BPO was selected as the preferred source of BPO services by US companies.

Indian firms have also taken several approaches to extend the benefits of this industry. NextWealth, an Indian service

outsourcing company, outsources the company's IT and services through a distributed delivery model (a type of service outsourcing model),<sup>[19]</sup> whereby many small delivery centers are set up in Tier 2, Tier 3, and Tier 4 cities, as well as in rural India. For the company, the lower cost of living in non-Tier 1 cities and the equally large pool of qualified, educated and relevantly trained labor means that a large, diverse and qualified talent pool can be accessed at lower wages, resulting in a considerable cost advantage. For employees, such distribution centers offer employment opportunities closer to home, which in turn increases employment rates. By operating in conjunction with local businesses, these distribution operations can be scaled up quickly and flexibly, with no reduction in revenue and quick break-even. The success of the industry in India has had a multiplier effect on the Indian economy, as this labor force is also a large consumer of goods and services, contributing to the growth of the Indian economy and the progress of the labor market.

GVC theory suggests that as countries become more integrated into global production networks, they benefit from increased demand for labor, higher wages, and better working conditions. This can help reduce income inequality and improve living standards. As multinational companies establish operations in developing countries, they often bring higher standards and better practices, contributing to improvements in the local labor market.

### **3.4 Economic Diversification**

Global value chains facilitate economic diversification, reducing reliance on a single industry or sector. GVC theory highlights the role of economic diversification in enhancing resilience and reducing inequality. By engaging in multiple sectors, countries can mitigate risks and ensure more stable growth.

Malaysia's integration into global electronics and automotive supply chains has significantly diversified its economy, making it more resilient and reducing economic inequality.<sup>[20]</sup> By developing multiple sectors, Malaysia has reduced its dependence on any single industry, enhancing economic stability. The electronics and automotive sectors have been pivotal in this diversification. Malaysia is a crucial player in the global semiconductor industry, supplying components essential for various electronic devices. This integration into the electronics supply chain has not only spurred economic growth but also created numerous job opportunities, contributing to a reduction in economic inequality. The automotive sector, particularly with the rise of electric vehicles (EVs), has further diversified Malaysia's industrial base. The transition towards EVs has reshaped the supply chain, creating new roles and opportunities for local suppliers and manufacturers, thus fostering economic resilience and stability. Moreover, Malaysia's location and well-developed infrastructure have attracted multinational corporations to set up manufacturing and supply chain operations in the country. This has led to increased foreign direct investment (FDI), technological transfers, and skill development among the local workforces. The Malaysian government has also implemented policies to support this diversification, such as improving digital infrastructure and promoting investment in high-tech industries. This is proved by the above theory as well as in the explanation of other examples. These efforts have collectively reduced Malaysia's economic vulnerability to global supply chain disruptions. By not being overly reliant on any single sector or market, Malaysia can better withstand economic shocks and maintain steady growth, contributing to a more equitable distribution of wealth across its population.<sup>[21]</sup>

GVC theory supports the opinion that economic diversification, driven by participation in global value chains, enhances economic stability and growth. This diversification helps to mitigate the risks associated with dependence on a single industry, contributing to a more equitable distribution of income and wealth. By developing various sectors, countries can create a more balanced and robust economy, reducing vulnerability to external shocks and fostering sustainable development.

## **4.Contexts and Conditions of the Benefits of Globalization**

This section will critically examine the contexts and conditions that influence the extent to which the benefits of globalization are realized. This analysis will consider how regional and national policies, institutional capacity, and social and economic infrastructure play crucial roles in determining the outcomes of globalization. We will analyze the existing examples from Part 2 to highlight these factors.

### **4.1 Regional and National Policies**

Strategic policies implemented by the State at the right time had a positive impact on reducing poverty and promoting its own economic development. The Korean Government had played an active role in guiding economic development and

implementing policies that supported industrialization and technology adoption. The Government's focus on building a strong export sector had been crucial to its economic transformation. Similarly, Singapore's strategy was focused on creating an enabling environment for foreign direct investment, making it a global economic hub. The success of these countries underscores the importance of active government intervention. Strategic policies such as the promotion of industrial growth and the development of an export economy had been crucial in taking advantage of the opportunities of globalization. These examples show that without supportive national policies, the potential benefits of globalization may not be fully realized.

## 4.2 Institutional Capacity and Governance

Strong institutions and effective governance are essential to manage the complexities of globalization and to ensure benefits from it. China's ability to implement and enforce economic reforms, establish special economic zones and attract foreign direct investment was central to its rapid economic growth. In promoting development, the Government had played an effective role by maintaining stable macroeconomic policies, providing infrastructure and supporting industrial policies. China's experience showed that strong institutional capacity and effective governance were essential to maximize the benefits of globalization. Effective governance structures enable countries to benefit the process of global integration, attract investment and distribute economic benefits more equitably. Conversely, countries with weak institutions may struggle to manage globalization effectively, leading to uneven development and persistent inequality.

## 4.3 Social and Economic Infrastructure

Investment in social and economic infrastructure, such as education, health care and transportation, was crucial to improving a country's ability to benefit from globalization. India's investment in education and technology infrastructure had led to the rapid growth of its IT sector. Initiatives to establish technology parks and strengthen higher education in engineering and computer science have enabled the development of a large skilled workforce capable of supporting the IT sector. The example of India highlighted the importance of social and economic infrastructure in realizing the benefits of globalization. Adequate infrastructure helped to produce efficiently, attract investment and increase productivity. Without such infrastructure, countries may find it difficult to compete globally and miss out on the potential benefits of globalization.

## 5. Conclusion

In conclusion, globalization has significantly contributed to reducing inequality and fostering economic development in many regions by promoting economic growth, facilitating technology and skills transfer, and enabling access to global markets. However, the realization of these benefits is highly dependent on specific contexts and conditions, including regional and national policies, institutional capacity, and social and economic infrastructure. By understanding and addressing these factors, countries can better harness the positive impacts of globalization and promote inclusive growth and improved living standards.

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# The Effect of Corporate Social Responsibility Information Disclosure on Total Factor Productivity

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**Abstract:** This study examines the impact mechanism of corporate social responsibility (CSR) information disclosure quality on total factor productivity (TFP) using data from Chinese A-share listed companies during 2010–2023. Employing a dual-pathway framework of resource aggregation and supervisory governance, we measure TFP via the LP and OP methods and analyze 39,844 firm-year observations through a mediation effect model. Results indicate that CSR disclosure quality significantly enhances firm-level TFP, with amplified effects in state-owned enterprises and firms audited by the Big Four. Mechanism tests demonstrate that CSR disclosure operates through four channels: alleviating financing constraints, optimizing human capital structure, intensifying media attention, and improving internal control quality. By integrating TFP into the analytical framework of CSR economic consequences, this research extends stakeholder and signaling theories, elucidating the micro-mechanisms through which sustainable development practices affect productivity. The conclusions provide empirical evidence for enterprises to optimize CSR strategies for productivity gains and for policymakers to refine disclosure regulatory systems, with implications for fostering high-quality development.

**Keywords:** Corporate Social Responsibility Disclosure; Total Factor Productivity; Resource Aggregation Effect; Supervisory Governance Effect

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## 1.Introduce

### 1.1 Research Background and Importance

In the contemporary global economy, the pursuit of sustainable development has become a central tenet for corporations worldwide. Stakeholders, including investors, regulators, and consumers, are increasingly demanding transparency regarding corporate performance beyond financial metrics, particularly in environmental, social, and governance (ESG) dimensions. Against this backdrop, Corporate Social Responsibility (CSR) disclosure has emerged as a critical non-financial communication tool, enabling firms to signal their commitment to long-term value creation and sustainable practices.

Concurrently, enhancing Total Factor Productivity (TFP) is universally recognized as the core driver of high-quality and sustainable economic growth, representing the efficiency with which all inputs are converted into output. While existing literature has extensively explored the impact of CSR disclosure on financial performance, its influence on firms' intrinsic operational efficiency—proxied by TFP—remains underexplored. This gap is significant, as understanding whether and how transparent sustainability reporting contributes to productive efficiency is crucial for both corporate strategy and academic



inquiry.

Most prior research focuses on the direct financial outcomes of CSR, such as firm value or cost of capital. However, scant attention has been paid to its effect on TFP, a more fundamental indicator of a firm's technological advancement and resource allocation efficiency. This study, therefore, seeks to bridge this gap by investigating the causal relationship between CSR disclosure quality and firm-level TFP. We propose a dual-pathway framework, hypothesizing that CSR disclosure influences TFP through both a resource-attraction effect (e.g., alleviating financing constraints, optimizing human capital) and a supervisory-governance effect (e.g., enhancing media monitoring, strengthening internal controls).

By empirically testing this framework using a large sample of Chinese listed firms, this research aims to provide robust, international evidence on the economic value of CSR disclosure. The findings will offer valuable insights for global managers seeking to leverage sustainability reporting for competitive advantage and for policymakers designing disclosure regulations to foster sustainable economic development.

## 1.2 Research Objectives

This study aims to systematically examine the impact mechanism and pathways through which Corporate Social Responsibility (CSR) information disclosure influences Total Factor Productivity (TFP). The core objectives are to empirically validate the direct promoting effect of CSR disclosure on TFP and to delve into its underlying transmission mechanisms, with a focus on the dual pathways of the "resource aggregation effect" (e.g., alleviating financing constraints and optimizing human capital) and the "supervisory governance effect" (e.g., enhancing media attention and strengthening internal control). Furthermore, the research explores the heterogeneous effects arising from contextual factors such as equity nature and audit quality, while ensuring the robustness of findings through methods including variable substitution and extended observation windows.

The research seeks to deepen the theoretical understanding of the economic consequences of CSR by transcending the traditional financial performance framework and revealing the value-creation mechanism of CSR practices from a productivity perspective. On a practical level, it aims to provide empirical evidence for enterprises to optimize information disclosure strategies and enhance TFP, as well as to offer insights for policymakers in designing disclosure regulatory systems that promote high-quality development.

## 2. Review of the literature

Although research on the economic consequences of corporate social responsibility (CSR) disclosure is already extensive, literature directly examining its impact on firm total factor productivity remains in a nascent stage. Scholars both domestically and internationally are gradually shifting their focus from traditional financial performance to efficiency indicators that better represent long-term competitiveness and high-quality development.

Foreign scholars have earlier explored the potential link between CSR disclosure and production efficiency from a theoretical perspective. Based on stakeholder theory and the resource-based view, firms build trust with key groups such as investors, employees, customers, and communities through CSR disclosure. The accumulation of this "social capital" helps firms access scarce resources (Sen, 2001), thereby providing support for production efficiency and innovation activities. For instance, empirical research by Mao (2022) found that firms consistently committed to sustainable development and actively disclosing related information, while not necessarily leading in stock performance and market valuation in the short term, demonstrated greater robustness in operational efficiency, innovation capability, and risk control. This indirectly suggests an enhancement in total factor productivity.

High-quality CSR disclosure is regarded as a positive signal that can effectively alleviate information asymmetry, reduce external investors' risk perception, and consequently help firms obtain capital at a lower cost (Margolis et al., 2009). The alleviation of financing constraints enables firms to allocate more resources to R&D, advanced equipment, and technological upgrades, directly promoting the improvement of total factor productivity (Meseguer-Sánchez et al., 2021). Firms with strong CSR performance are more likely to attract and retain high-quality talent (Tunio et al., 2021). Simultaneously, disclosure related to employee welfare and training reflects the firm's investment in human capital. This can stimulate employee innovation and enhance internal process efficiency, serving as a core micro-foundation for driving growth in total factor

productivity (Mukhuty et al., 2022). CSR disclosure requires firms to establish more robust internal management and data collection systems, which inherently strengthens internal controls (Lozano et al., 2009). Sound internal controls can reduce agency costs and inefficient investments, optimizing resource allocation. Furthermore, disclosing environmental and social risk information helps firms identify and mitigate operational risks (e.g., environmental incidents, supply chain disputes) that could disrupt production, thereby safeguarding the stability of production processes (Liang et al., 2022).

It is noteworthy that some studies point to potential negative or complex relationships. For example, excessive or unrealistic CSR investments may divert productive resources, increase management costs, and negatively impact efficiency in the short term (Li, 2022). Additionally, this relationship is significantly influenced by the institutional environment. The productivity effect of CSR disclosure tends to be more pronounced in regions with stronger investor protection and more developed market mechanisms (Hawn, 2016).

### **3. Research methodology**

#### **3.1 Research hypotheses**

Against the backdrop of global sustainable development and the rise of ESG investing, corporate social responsibility (CSR) information disclosure has become a vital component of strategic corporate management. As China's economy transitions towards high-quality development, enhancing total factor productivity (TFP) stands as a core pathway for optimizing economic structure. Investigating the impact of CSR disclosure on TFP therefore holds significant theoretical and policy implications (Li, 2022).

Grounded in signaling theory, CSR disclosure serves a crucial signaling function in markets characterized by information asymmetry. Systematically disclosed sustainability reports convey positive information about sound corporate governance and long-term potential to stakeholders, thereby enhancing market trust and improving the business operating environment. From the perspective of stakeholder theory, CSR disclosure facilitates the establishment of constructive, long-term relationships with investors, employees, customers, and other parties, creating favorable conditions for TFP improvement (Ni, 2019).

The mechanisms through which CSR disclosure influences TFP are manifested in the following pathways: First, it reduces financing costs through a signaling effect, providing capital support for technological innovation (Clarkson, 2008). Second, it attracts high-caliber talent via a reputation mechanism, optimizing the structure of human capital. Third, it strengthens internal controls, thereby improving the efficiency of resource allocation. Fourth, it introduces external supervision, which helps constrain managerial conduct. Finally, it enhances operational stability through process optimization. Together, these pathways constitute a multi-channel transmission framework through which CSR affects TFP (David, 2016).

Based on the foregoing analysis, this paper proposes the following research hypothesis:

H1: Corporate social responsibility disclosure has a significant positive impact on enterprise total factor productivity.

Against the backdrop of growing ESG adoption, corporate social responsibility (CSR) disclosure has emerged as a significant mechanism influencing investor decisions, mitigating financing constraints, and ultimately enhancing total factor productivity (TFP) (Sheldon, 1924). Grounded in information asymmetry theory and signaling theory, proactive and high-quality CSR disclosure conveys positive signals to the market regarding sound corporate governance, lower risk profiles, and long-term value, thereby distinguishing firms from lower-quality peers and strengthening trust among external investors and creditors. Stakeholder theory further suggests that such disclosure helps shape a responsible corporate image, improves commercial credit and debt financing conditions, and significantly reduces the risk perception and financing costs imposed by external capital providers (Bowen, 1984).

The alleviation of financing constraints enables firms to concretize investments in long-term R&D, technological upgrades, and advanced equipment, reducing underinvestment and resource misallocation caused by capital shortages (Davis, 1960). Consequently, management is better positioned to support innovation initiatives and technological transformation projects that, despite longer cycles, contribute to fundamental efficiency gains, thereby directly promoting TFP growth (Carroll, 1991). Based on the logic of the "resource attraction effect," this paper proposes the following hypothesis:

H2: Corporate social responsibility disclosure positively affects enterprise total factor productivity by alleviating financing

constraints.

#### Impact through Optimizing Human Capital Structure (Resource Attraction Effect)

In today's sustainability-oriented business environment, CSR disclosure serves as a strategic tool for attracting, motivating, and retaining high-quality talent (Siegel, 2001). From a human capital theory perspective, CSR disclosure essentially constitutes an investment in human capital. By shaping a favorable employer brand, it reduces recruitment and training costs, enhances the quality of the talent structure, and thereby strengthens the firm's knowledge accumulation and innovation capabilities, providing an intellectual foundation for TFP improvement (Fama, 1971).

Social identity theory further elucidates that firms actively fulfilling social responsibilities enhance employees' sense of belonging, identification, and pride, which translates into higher work engagement and organizational loyalty, improving overall operational efficiency (Cheng, 2014). According to signaling theory, given the information asymmetry in the labor market, CSR disclosure sends positive signals to potential and current employees regarding employee care, cultural atmosphere, and ethical standards, helping firms establish a competitive advantage in talent attraction—particularly among value-driven, younger knowledge workers (Hemingway, 2004).

Through these mechanisms, CSR disclosure optimizes the structure and quality of human capital. A highly competent and identified workforce not only drives technological innovation but also enhances organizational learning, adaptability, and continuous improvement capabilities, thereby pushing the production technology frontier outward and supporting long-term TFP growth (Akerberg, 2010).

Based on the above analysis, this paper proposes the following hypothesis:

H3: Corporate social responsibility disclosure positively affects enterprise total factor productivity by optimizing the human capital structure.

#### Impact through Enhancing Media Attention (Supervisory Governance Effect)

Media attention, as an important external governance mechanism, plays a key transmitting and reinforcing role in the process through which CSR disclosure affects TFP (Akerberg, 2010). Corporate disclosure of social responsibility information conveys positive non-financial signals to the market, easily triggering media coverage and focus, thereby forming effective external supervision (Akerberg, 2010).

According to agenda-setting theory, media guides public attention by selecting and emphasizing specific issues. Detailed CSR reports provide positive material for media, turning corporate social performance into a public issue and attracting sustained attention (Caggese, 2013). This scrutiny places corporate behavior under broad public supervision, compensating to some extent for deficiencies in internal corporate governance and alleviating principal-agent problems.

From a reputation mechanism perspective, media attention is directly linked to corporate and managerial reputation. Positive coverage builds reputational capital and enhances stakeholder trust, while negative exposure may trigger reputational risks, increasing financing costs and legal pressures (Midrigan, 2014). To protect their reputation, management is motivated to improve operational transparency, increase innovation investment, optimize resource allocation, and commit to long-term value creation, thereby avoiding market penalties associated with short-term opportunistic behavior (Restuccia, 2008).

Furthermore, media scrutiny reduces information asymmetry between the firm and external parties, helps bolster market confidence, alleviates financing constraints, and provides more stable funding support for technological upgrades (Gopinath, 2017). Under media attention, management is also more inclined to direct resources towards more efficient production activities and innovation, thereby improving resource allocation efficiency and laying the groundwork for sustained TFP growth (Bond, 2017).

In summary, this paper proposes the following hypothesis:

H4: Corporate social responsibility disclosure positively affects enterprise total factor productivity by enhancing media attention.

#### Impact through Improving Internal Control Quality (Supervisory Governance Effect)

Internal control, as a core mechanism of internal corporate governance, reveals an important pathway through which CSR disclosure affects TFP. CSR disclosure is not only a means of external communication but also a significant process for

internal management optimization (Bloom, 2007). Based on principal-agent theory, mandatory and voluntary disclosure requirements compel management to regularly report social and environmental performance to stakeholders (Bloom, 2014). This transparency mechanism curbs managerial opportunistic behavior and promotes systematic improvement of the internal control system (Bender, 2018).

To fulfill disclosure commitments, firms must establish standardized mechanisms for information collection, processing, and reporting, achieving standardization of management processes (Fleisher, 2010). This includes setting up data monitoring and evaluation systems for key areas such as environmental management, employee rights, and supply chain responsibility, which directly enhances the overall quality of internal controls (Chiang, 2007).

The improvement of the internal control system further directly benefits TFP by standardizing business processes, reducing operational risks, and enhancing resource utilization efficiency (Tian, 2011). Simultaneously, sound internal controls optimize corporate decision-making mechanisms, increase investment, reduce inefficient investment, and strengthen constraints and incentives for management, encouraging a focus on long-term value creation and thereby improving overall operational efficiency (Min, 2014).

Based on the aforementioned "supervisory governance effect" pathway, this paper proposes the following hypothesis:

H5: Corporate social responsibility disclosure positively affects enterprise total factor productivity by improving internal control quality.

## 3.2 Model specification

### 3.2.1 Baseline regression model

To examine the impact of corporate social responsibility (CSR) disclosure on total factor productivity (TFP) (Hypothesis H1), the following baseline regression model is constructed:

$$TFP_{i,t} = \beta_0 + \beta_1 CSR_{i,t} + \beta Controls_{i,t} + \delta_i + \theta_t + \varepsilon_{i,t} \quad (3-1)$$

$TFP_{i,t}$  is the dependent variable, representing the total factor productivity. TFP is measured using both the LP method (TFP\_LP) and the OP method (TFP\_OP).  $CSR_{i,t}$  is the core explanatory variable, representing the quality of CSR disclosure (CSR1).  $Controls_{i,t}$  is a vector of control variables, which includes firm size (Size), profitability (Roa), financial leverage (Lev), cash flow (Cash), growth (Growth), board size (Board), the proportion of independent directors (Indep), ownership concentration (Top1), institutional investor shareholding (Inst), and firm age (Age).  $\delta_i$  and  $\theta_t$  denote industry and year fixed effects, respectively.  $\varepsilon_{i,t}$  is the random error term.

### 3.2.2 Mechanism test models

To test the mediating mechanisms of the resource attraction effect (financing constraints and human capital structure) and the supervisory governance effect (media attention and internal control quality), and to validate Hypotheses H2a, H2b, H3a, and H3b, we follow the mediation effect test procedure proposed by Wen et al. (2004) and construct the following models:

$$M_{i,t} = \alpha_0 + \alpha_1 CSR_{i,t} + \alpha Controls_{i,t} + \delta_i + \theta_t + \varepsilon_{i,t} \quad (3-2)$$

$$TFP_{i,t} = \gamma_0 + \gamma_1 CSR_{i,t} + \gamma_2 M_{i,t} + \gamma Controls_{i,t} + \delta_i + \theta_t + \varepsilon_{i,t} \quad (3-3)$$

Here,  $M_{i,t}$  represents the mediating variable. For the resource attraction effect path,  $M_{i,t}$  denotes financing constraints (SA\_abs, where a larger value indicates more severe constraints) and human capital structure (RL, the proportion of employees with a bachelor's degree or higher). For the supervisory governance effect path,  $M_{i,t}$  denotes media attention (Media, the natural logarithm of one plus the number of media reports) and internal control quality (IC, the natural logarithm of the DIB index).

First, Equation (2) examines the effect of the explanatory variable CSR on the mediating variable M (coefficient  $\alpha_1$ ). Subsequently, Equation (3) incorporates the mediating variable M into the baseline regression to test the direct effect of CSR on TFP (coefficient  $\gamma_1$ ) and the effect of the mediating variable M on TFP (coefficient  $\gamma_2$ ). A significant  $\alpha_1$  and  $\gamma_2$  together indicate the presence of a mediating effect.

## 3.3 Data

### 3.3.1 Samples

This study selects data from A-share listed companies on the Shanghai and Shenzhen stock exchanges for the period 2010–2023 as the initial sample. The data were processed as follows. First, ST and \*ST companies were excluded. Second, because the financial data of financial firms differ significantly from those of non-financial firms, listed financial companies were removed. Third, observations with missing or abnormal data were excluded. Finally, all continuous variables were winsorized at the 1% and 99% levels. After the above screening, a final sample of 39,844 firm-year observations was obtained.

The data sources are as follows: basic financial data were sourced from the CSMAR database, corporate social responsibility information was obtained from the Social Responsibility Research Database within CSMAR, and media attention data were collected from the CNRDS database, among other sources. Data processing was conducted using Excel and Stata 18.

### 3.3.2 Measurement of the explained variables

Total Factor Productivity (TFP) serves as a core comprehensive indicator for measuring the efficiency with which firms translate given factor inputs into output. Its accurate measurement is crucial for ensuring the reliability of empirical findings. Traditional Ordinary Least Squares (OLS) estimation of production functions suffers from simultaneity bias—where firms adjust input levels in response to observed productivity shocks—and sample selection bias arising from firms' entry and exit decisions based on productivity. To address these endogeneity concerns, this study employs more rigorous semi-parametric estimation methods.

Specifically, we concurrently apply the OP method proposed by Olley and Pakes (1992) and the LP method developed by Levinsohn and Petrin (2003). Both approaches control for unobservable productivity shocks by introducing proxy variables, yet they differ in their mechanisms and applicability:

The OP method uses firm investment as the proxy variable. However, investment can be influenced by external factors such as financing constraints, potentially failing to fully capture genuine productivity changes. Moreover, this method suffers from sample loss due to zero-investment observations.

The LP method, in contrast, employs intermediate input as the proxy. Intermediate input typically responds more sensitively to productivity variations and effectively avoids sample attrition caused by zero investment. Nevertheless, it may also be affected by non-productivity factors, such as supply chain fluctuations.

To enhance the robustness of our conclusions and following the approach of Tian (2011), this paper calculates TFP using both methods, enabling cross-validation and comparative analysis.

### 3.2.3 Measurement of explanatory variables

The core explanatory variable of this study is the quality of corporate social responsibility (CSR) information disclosure. Drawing on the research of Dhaliwal (2012), this variable is measured along two dimensions: disclosure behavior and disclosure quality. Specifically, disclosure behavior is represented by a dummy variable, which takes a value of 1 if the company publishes a CSR report or relevant information in that year, and 0 otherwise. Disclosure quality is assessed based on stakeholder theory, following the approach of Clarkson (1995). This involves a comprehensive evaluation based on 12 key aspects covered in CSR reports from the CSMAR database. A binary scoring method is applied to each aspect, and the total scores are summed. The final CSR disclosure quality index is then standardized to a range of 0 to 1, with higher values indicating better quality of CSR information disclosure.

*Table 1. Core conceptual definitions*

Variable type classification	Variable naming principles	Symbol design specifications	Measurement method description framework
Dependent variable	Total factor productivity	TFP_LP	Total factor productivity of the firm in the current year measured using the LP method
		TFP_OP	Total factor productivity of the firm in the current year measured using the OP method
Explanatory variable	Corporate social responsibility disclosure quality	CSR1	Score obtained based on relevant indicators of social responsibility information disclosure in the CSMAR Social Responsibility Database, standardized



Variable type classification	Variable naming principles	Symbol design specifications	Measurement method description framework
Mediating variable	Financing constraints	SA_abs	Absolute value of the SA index
	Human capital structure	RL	Number of employees with a bachelor's degree or higher / Total number of employees
	Media attention	Media	Natural logarithm of (number of media reports + 1)
	Internal control	IC	Natural logarithm of the DIB index
	Firm size	Size	Natural logarithm of total assets at year-end
	Return on assets	Roa	Net profit / Total assets
	Asset-liability ratio	Lev	Total liabilities at year-end / Total assets at year-end
	Cash flow ratio	Cash	Net cash flow from operating activities / Total assets
Control variable	Operating revenue growth rate	Growth	(Operating revenue of the current year / Operating revenue of the previous year) – 1
	Board size	Board	Natural logarithm of the number of board members
	Proportion of independent directors	Indep	Number of independent directors / Total number of board members
	Shareholding ratio of the largest shareholder	Top1	Number of shares held by the largest shareholder / Total number of shares
	Proportion of institutional investors' shareholding	Inst	Number of shares held by institutional investors / Total number of shares
	Firm age	Age	Natural logarithm of (current year – firm founding year + 1)

## 4. An empirical analysis

### 4.1 Descriptive statistics

The full sample comprises 39,844 firm-year observations, with no missing values for any variables. Under the two measurement approaches for the core dependent variable, total factor productivity (TFP), the mean values are 8.956 (LP method) and 6.612 (OP method), respectively, with significant variation across firms (standard deviations of 1.098 and 0.881, respectively). The core explanatory variable, corporate social responsibility information disclosure (CSR1), has a mean of 0.457 and a median of 0.583, indicating a slightly left-skewed distribution, with the majority of firms exhibiting disclosure levels above the mean. The relatively high standard deviation of CSR1 reflects substantial variation in disclosure quality across firms, which provides a basis for investigating the heterogeneous effects of CSR. Regarding the control variables, the distributional characteristics of firm size (Size), profitability (Roa), financial leverage (Lev), and others are consistent with existing literature and align with the general patterns observed in Chinese listed companies. It is particularly noteworthy that the standard deviation of firm growth (Growth) is relatively high (1.111), indicating that the sample includes firms at different growth stages, thereby enhancing the representativeness of the sample.

Table 2. Descriptive statistics

Variable	N	Mean	Med	SD	Min	Max
TFP_LP	39844	8.956	8.851	1.098	5.919	12.065
TFP_OP	39844	6.612	6.509	0.881	4.387	9.225
CSR1	39844	0.457	0.583	0.260	0.000	1.000
Size	39844	7.652	7.573	1.254	4.060	11.181
Roa	39844	0.033	0.034	0.067	-0.556	0.222



Variable	N	Mean	Med	SD	Min	Max
Lev	39844	0.429	0.422	0.205	0.028	0.908
Cash	39844	0.046	0.045	0.069	-0.222	0.267
Growth	39844	0.369	0.120	1.111	-0.928	17.107
Board	39844	2.117	2.197	0.198	1.609	2.708
Indep	39844	0.377	0.364	0.054	0.286	0.600
Top1	39844	0.340	0.317	0.147	0.078	0.758
Inst	39844	0.437	0.451	0.245	0.001	0.923
Age	39844	2.957	2.996	0.328	1.099	3.689

## 4.2 Baseline regression analysis

This study employs total factor productivity (TFP) calculated using both the LP and OP methods as the core dependent variable. The regression results for the LP method (TFP\_LP) are presented in Table 3.

Model (1) is a simple regression containing only the CSR1 variable. Its coefficient is 1.105 ( $t=54.173$ ), which is significantly positive at the 1% level. After including year and industry fixed effects in Model (2), the coefficient of CSR1 slightly decreases to 1.084 ( $t=53.277$ ) while retaining its significance. This indicates that the positive effect of CSR1 on TFP\_LP remains robust after controlling for time trends and industry heterogeneity. Model (3) further incorporates control variables. The coefficient of CSR1 decreases to 0.409 ( $t=27.686$ ) but remains significant at the 1% level, suggesting that the positive impact of corporate social responsibility (CSR) information disclosure quality on TFP is partially mediated through firm characteristics. Model (4) represents the full model, including both control variables and fixed effects. The coefficient of CSR1 is 0.282 ( $t=19.529$ ) and significantly positive, confirming that improvements in CSR disclosure quality effectively enhance firm-level TFP.

Regarding the control variables, the coefficient for firm size (Size) is 0.437 ( $t=129.188$ ) and significantly positive, indicating that economies of scale contribute to improved production efficiency. The coefficient for profitability (Roa) is 3.081 ( $t=52.536$ ) and highly significant, suggesting that firms with stronger profitability can more easily accumulate resources for productivity enhancement. The coefficient for financial leverage (Lev) is 1.393 ( $t=66.468$ ) and significantly positive, implying that moderate debt may promote productivity growth through tax shield effects and investment expansion. Corporate governance variables, including board size (Board), the proportion of independent directors (Indep), ownership concentration (Top1), and institutional investor shareholding (Inst), are all significantly positive, confirming the positive role of sound corporate governance in enhancing TFP.

Table 3. LP method baseline regression analysis table

Variable name	(1)	(2)	(3)	(4)
	TFP_LP	TFP_LP	TFP_LP	TFP_LP
CSR1	1.105*** (54.173)	1.084*** (53.277)	0.409*** (27.686)	0.282*** (19.529)
Size			0.407*** (114.563)	0.437*** (129.188)
Roa			3.149*** (49.548)	3.081*** (52.536)
Lev			1.755*** (82.987)	1.393*** (66.468)

Variable name	(1)	(2)	(3)	(4)
	TFP_LP	TFP_LP	TFP_LP	TFP_LP
Cash			-0.212*** (-3.623)	0.009 (0.167)
Growth			0.005 (1.549)	-0.005 (-1.434)
Board			0.008 (0.328)	0.111*** (5.187)
Indep			0.436*** (5.336)	0.445*** (6.001)
Top1			0.175*** (5.968)	0.079*** (2.927)
Inst			0.456*** (24.383)	0.416*** (23.961)
Age			0.283*** (24.531)	0.021* (1.726)
_cons	8.451*** (787.812)	8.089*** (165.557)	3.532*** (45.423)	3.499*** (44.581)
Ind	NO	YES	NO	YES
Year	NO	YES	NO	YES
N	39844	39844	39844	39844
Adj R <sup>2</sup>	0.069	0.234	0.563	0.645
F	2934.696	203.296	4668.601	1036.088

To verify the robustness of the results, this study also conducted regression analysis using total factor productivity measured by the OP method (TFP\_OP) as the dependent variable, as shown in Table 4. In the simple regression of Model (1), the coefficient of CSR1 is 0.722 (t=43.572), which is significant at the 1% level. After including fixed effects in Model (2), the coefficient becomes 0.650 (t=40.669) while retaining its significance. In Model (3), which incorporates control variables, the coefficient of CSR1 is 0.432 (t=29.585), and in the full Model (4), the coefficient is 0.293 (t=20.498), both of which remain significantly positive. These results are consistent with the findings obtained using the LP method, further confirming that the quality of corporate social responsibility information disclosure has a significantly positive impact on firm-level total factor productivity.

Table 4. OP method baseline regression analysis table

Variable name	(1)	(2)	(3)	(4)
	TFP_OP	TFP_OP	TFP_OP	TFP_OP
CSR1	0.722*** (43.572)	0.650*** (40.669)	0.432*** (29.585)	0.293*** (20.498)
Size			0.078*** (22.248)	0.108*** (32.318)

Variable name	(1)	(2)	(3)	(4)
	TFP_OP	TFP_OP	TFP_OP	TFP_OP
Roa			3.089*** (49.165)	3.024*** (52.068)
Lev			1.773*** (84.808)	1.406*** (67.717)
Cash			-0.107* (-1.858)	0.065 (1.213)
Growth			0.001 (0.209)	-0.006* (-1.914)
Board			0.048** (2.074)	0.139*** (6.540)
Indep			0.506*** (6.265)	0.518*** (7.052)
Top1			0.177*** (6.106)	0.066** (2.449)
Inst			0.479*** (25.891)	0.432*** (25.116)
Age			0.289*** (25.329)	0.021* (1.756)
_cons	6.282*** (721.165)	5.859*** (152.698)	3.545*** (46.131)	3.573*** (45.973)
Ind	NO	YES	NO	YES
Year	NO	YES	NO	YES
N	39844	39844	39844	39844
Adj R <sup>2</sup>	0.045	0.265	0.337	0.459
F	1898.477	240.923	1838.228	484.459

The baseline regression results consistently show that the quality of corporate social responsibility information disclosure (CSR1) has a significant positive effect on corporate total factor productivity (both TFP\_LP and TFP\_OP), supporting the research hypothesis and indicating that the research conclusions are robust to different measurement methods of total factor productivity.

### 4.3 Mediating effect test

Based on the research hypotheses and baseline regression results, corporate social responsibility (CSR) information disclosure significantly promotes corporate total factor productivity. To delve deeper into the underlying pathways, this study further conducts mechanism tests from the theoretical dimensions of the "resource aggregation effect" and the "supervision and governance effect." Specifically, it examines the roles of four mediating variables: financing constraints (SA\_abs), human capital structure (RL), media attention (Media), and internal control (IC). To enhance the robustness of the conclusions, this study sequentially employs the Baron & Kenny three-step method for preliminary path verification. It is supplemented with the Sobel test and the Bootstrap sampling method (500 repetitions) to strictly assess the statistical significance of the mediating effects.

#### 4.3.1 Mediating mechanism test of the resource aggregation effect

Columns (1)-(3) in Table 5 show that the coefficient of corporate social responsibility information disclosure (CSR1) on financing constraints (SA\_abs) is -0.022, which is significantly negative at the 1% level ( $t = -8.714$ ). This indicates that a higher level of CSR disclosure is associated with lower corporate financing constraints. After controlling for the financing constraints variable, the coefficients of CSR1 on TFP\_LP and TFP\_OP remain significantly positive (0.272 and 0.282, respectively), and financing constraints themselves have a significantly negative impact on TFP (coefficients of -0.445 and -0.490, respectively). The Sobel test Z-values are 7.598 (TFP\_LP) and 7.778 (TFP\_OP), far exceeding the critical value of 1.96. The 95% confidence intervals from Bootstrap sampling are [0.008, 0.012] for TFP\_LP and [0.008, 0.013] for TFP\_OP, both of which do not contain zero, confirming the robustness of the results. This suggests that CSR information disclosure promotes total factor productivity by alleviating external financing constraints, thereby providing more stable financial support for the enterprise. Hypothesis H2 is supported.

Columns (4)-(6) indicate that the coefficient of CSR information disclosure (CSR1) on human capital structure (RL) is 0.044, which is significant at the 1% level ( $t = 11.152$ ). This suggests that CSR disclosure helps attract and retain highly educated talent, thereby optimizing the firm's human capital. After introducing the RL variable, the coefficients of CSR1 on TFP\_LP and TFP\_OP remain significantly positive (0.216 and 0.228, respectively), and RL itself has a significant positive effect on TFP (coefficients of 1.328 and 1.310, respectively). The Sobel Z-value is 10.96, and the Bootstrap confidence interval does not contain zero, confirming the significant mediating effect of human capital structure. This implies that by disclosing CSR information, firms shape a positive employer image, attract high-quality talent, provide intellectual support for technological innovation and efficiency improvements, and ultimately drive total factor productivity growth. Hypothesis H3 is validated.

Table 5. The three-step mechanism test

Variable name	(1)	(2)	(3)	(4)	(5)	(6)
	SA_abs	TFP_LP	TFP_OP	RL	TFP_LP	TFP_OP
CSR1	-0.022*** (-8.714)	0.272*** (18.891)	0.282*** (19.802)	0.044*** (11.152)	0.216*** (13.851)	0.228*** (14.819)
SA_abs		-0.445*** (-15.521)	-0.490*** (-17.248)			
RL					1.328*** (59.093)	1.310*** (58.927)
Size	-0.013*** (-22.547)	0.431*** (127.013)	0.102*** (30.295)	-0.039*** (-41.207)	0.498*** (132.563)	0.169*** (45.480)
Roa	0.080*** (7.859)	3.117*** (53.265)	3.064*** (52.901)	0.228*** (14.472)	2.565*** (41.542)	2.510*** (41.106)
Lev	0.000 (0.098)	1.393*** (66.676)	1.406*** (67.977)	0.063*** (10.843)	1.296*** (57.002)	1.312*** (58.338)
Cash	-0.005 (-0.485)	0.007 (0.130)	0.063 (1.176)	-0.120*** (-8.061)	0.270*** (4.637)	0.326*** (5.647)
Growth	-0.001* (-1.743)	-0.005 (-1.574)	-0.007** (-2.071)	0.016*** (17.474)	-0.022*** (-6.146)	-0.024*** (-6.641)
Board	-0.013*** (-3.462)	0.106*** (4.932)	0.133*** (6.264)	0.077*** (12.992)	0.010 (0.438)	0.039* (1.703)
Indep	-0.174***	0.367***	0.433***	0.222***	0.111	0.190**

Variable name	(1)	(2)	(3)	(4)	(5)	(6)
	SA_abs	TFP_LP	TFP_OP	RL	TFP_LP	TFP_OP
	(-13.438)	(4.962)	(5.903)	(10.942)	(1.397)	(2.413)
Top1	-0.010**	0.075***	0.061**	-0.047***	0.108***	0.093***
	(-2.144)	(2.769)	(2.273)	(-6.417)	(3.764)	(3.260)
Inst	-0.021***	0.407***	0.422***	0.110***	0.235***	0.252***
	(-6.927)	(23.480)	(24.595)	(23.339)	(12.596)	(13.684)
Age	0.719***	0.341***	0.373***	-0.016***	0.030**	0.031**
	(344.369)	(14.299)	(15.809)	(-4.799)	(2.359)	(2.429)
_cons	1.958***	4.371***	4.532***	0.264***	4.075***	4.118***
	(143.154)	(45.376)	(47.544)	(2.863)	(11.290)	(11.535)
Ind	YES	YES	YES	YES	YES	YES
Year	YES	YES	YES	YES	YES	YES
N	39844	39844	39844	30384	30384	30384
Adj R <sup>2</sup>	0.810	0.647	0.463	0.451	0.690	0.527
F	2434.801	1031.050	485.386	362.063	968.554	484.398
Sobel Z		7.598	7.778		10.96	10.96
Bootstrap		[0.008,0.012]	[0.008,0.013]		[0.052,0.066]	[0.049,0.067]

#### 4.3.2 Mediating mechanism test of the supervision and governance effect

As shown in column (1) of Table 6, the coefficient of corporate social responsibility information disclosure (CSR1) on media attention (Media) is 0.254, which is significantly positive at the 1% level. This indicates that a higher level of CSR disclosure corresponds to greater media attention received by the firm. Columns (2)-(3) show that after controlling for the media attention variable, the coefficients of CSR1 on TFP\_LP and TFP\_OP remain significantly positive (0.258 and 0.268, respectively), and media attention itself has a significant positive effect on TFP (coefficients of 0.099 and 0.103, respectively). The Sobel test Z-values are 11.79 (for TFP\_LP) and 11.90 (for TFP\_OP), far exceeding the critical value of 1.96. The 95% confidence intervals from Bootstrap sampling are [0.021, 0.029] and [0.022, 0.030], respectively, neither of which includes zero, confirming the robustness of the results. This suggests that CSR information disclosure promotes total factor productivity by enhancing media attention, thereby strengthening external supervision and information transparency. Hypothesis H4 is supported.

Column (4) of Table 5-13 indicates that CSR information disclosure contributes to the improvement of the firm's internal control system. Columns (5) and (6) show that after introducing the IC variable, the coefficients of CSR1 on TFP\_LP and TFP\_OP remain significantly positive, and IC itself has a significant positive effect on TFP. The Sobel Z-values are far greater than the critical value, and the Bootstrap confidence intervals do not include zero, confirming the significant mediating effect of internal control. This implies that by disclosing CSR information, firms are driven to standardize internal management processes and enhance risk control capabilities, thereby providing institutional safeguards for the growth of total factor productivity. Hypothesis H5 is validated.

Table 6. The three-step mechanism test

Variable name	(1)	(2)	(3)	(4)	(5)	(6)
	IC	TFP_LP	TFP_OP	Media	TFP_LP	TFP_OP
CSR1	0.149*** (6.908)	0.279*** (19.070)	0.291*** (20.048)	0.254*** (13.283)	0.258*** (17.683)	0.268*** (18.608)
IC		0.031*** (8.935)	0.031*** (9.133)			
Media					0.099*** (25.633)	0.103*** (26.794)
Size	0.065*** (12.852)	0.438*** (126.805)	0.109*** (31.978)	0.254*** (56.591)	0.411*** (115.827)	0.081*** (23.186)
Roa	3.717*** (41.300)	3.023*** (48.531)	2.952*** (47.851)	0.954*** (12.118)	3.064*** (51.168)	2.999*** (50.600)
Lev	-0.294*** (-9.311)	1.417*** (66.175)	1.427*** (67.246)	0.378*** (13.535)	1.368*** (64.383)	1.378*** (65.559)
Cash	-0.392*** (-4.777)	0.041 (0.745)	0.099* (1.804)	0.086 (1.195)	-0.028 (-0.506)	0.029 (0.532)
Growth	0.007 (1.367)	-0.007** (-2.099)	-0.008** (-2.552)	0.013*** (3.193)	-0.005* (-1.710)	-0.007** (-2.251)
Board	-0.005 (-0.152)	0.114*** (5.202)	0.142*** (6.542)	0.248*** (8.712)	0.081*** (3.738)	0.108*** (5.036)
Indep	0.034 (0.310)	0.447*** (5.930)	0.526*** (7.046)	1.509*** (15.384)	0.279*** (3.728)	0.347*** (4.687)
Top1	0.271*** (6.726)	0.074*** (2.691)	0.059** (2.193)	-0.441*** (-12.312)	0.123*** (4.526)	0.111*** (4.100)
Inst	-0.184*** (-7.123)	0.404*** (23.027)	0.422*** (24.319)	0.254*** (10.982)	0.396*** (22.513)	0.411*** (23.644)
Age	-0.084*** (-4.701)	0.024* (1.942)	0.024** (2.003)	-0.211*** (-13.328)	0.044*** (3.629)	0.045*** (3.733)
_cons	6.033*** (51.238)	3.276*** (39.730)	3.346*** (40.972)	2.808*** (27.060)	3.225*** (40.541)	3.291*** (41.799)
Ind	YES	YES	YES	YES	YES	YES
Year	YES	YES	YES	YES	YES	YES
N	37931	37931	37931	38529	38529	38529
Adj R <sup>2</sup>	0.084	0.651	0.466	0.494	0.653	0.472
F	50.386	999.087	467.293	537.724	1022.781	486.443
Sobel Z		5.465	5.51		11.79	11.9
Bootstrap		[0.002,0.006]	[0.003,0.007]		[0.021,0.029]	[0.022,0.030]



## 4.4 Robustness tests

### 4.4.1 Replacing the explained variable and explanatory variable

In measuring corporate total factor productivity, this paper employs both the LP method and the OP method, and adopts the CSR disclosure quality measurement method CSR1 proposed by Zou Ping. To further verify the robustness of the research conclusions, this paper conducts supplementary tests by replacing variables.

First, this paper uses the total factor productivity measured by the OLS method (TFP\_OLS) as the new explained variable for regression analysis. As shown in column (1) of Table 7, the coefficient of the explanatory variable CSR1 is 0.329, which is significantly positive at the 1% level ( $t = 21.970$ ). This result is entirely consistent with the estimation results using the LP and OP methods in the baseline regression in terms of sign direction and significance level, indicating that regardless of the TFP measurement method used, the quality of corporate social responsibility information disclosure has a significant promoting effect on total factor productivity.

Second, this paper adopts another corporate social responsibility disclosure quality indicator, CSR2 (a count measure constructed based on a company's disclosure performance across eight CSR aspects, where a value closer to 8 indicates better CSR fulfillment), to replace the original explanatory variable. The regression results with TFP\_LP and TFP\_OP as the explained variables are shown in columns (2) and (3) of Table 7, respectively. When the explained variable is TFP\_LP, the coefficient of CSR2 is 0.023, significant at the 1% level ( $t = 16.084$ ). When the explained variable is TFP\_OP, the coefficient of CSR2 is 0.024, also significant at the 1% level ( $t = 16.869$ ). Although the coefficient values differ from those of CSR1 in the baseline regression, the sign direction and significance level are completely consistent. This suggests that CSR disclosure quality measured in different ways can significantly enhance corporate total factor productivity.

Through the robustness tests involving replacing the explained and explanatory variables described above, this paper finds that regardless of the TFP measurement method (OLS, LP, or OP) or the CSR disclosure quality indicator (CSR1 or CSR2) used, the coefficient of the core explanatory variable remains significantly positive at least at the 1% level. Furthermore, the goodness-of-fit ( $R^2$ ) and F-statistics of each regression model remain at high levels, and the signs and significance of the control variables show no substantial changes. These results indicate that the promoting effect of corporate social responsibility information disclosure quality on total factor productivity is highly robust, confirming the reliability of the research conclusions.

Table 7. Variable replacement

Variable name	(1)	(2)	(3)
	TFP_OLS	TFP_LP	TFP_OP
CSR1	0.329*** (21.970)		
CSR2		0.023*** (16.084)	0.024*** (16.869)
Size	0.567*** (161.852)	0.440*** (130.857)	0.112*** (33.666)
Roa	2.995*** (49.250)	3.090*** (52.610)	3.033*** (52.142)
Lev	1.518*** (69.828)	1.391*** (66.283)	1.404*** (67.515)
Cash	0.178*** (3.181)	0.011 (0.211)	0.067 (1.258)
Growth	-0.012*** (-3.575)	-0.005 (-1.463)	-0.006* (-1.944)

Variable name	(1)	(2)	(3)
	TFP_OLS	TFP_LP	TFP_OP
Board	0.205*** (9.201)	0.116*** (5.375)	0.143*** (6.735)
Indep	0.675*** (8.787)	0.457*** (6.164)	0.531*** (7.221)
Top1	0.081*** (2.887)	0.077*** (2.841)	0.063** (2.359)
Inst	0.489*** (27.164)	0.424*** (24.378)	0.440*** (25.549)
Age	0.021* (1.711)	0.020 (1.644)	0.020* (1.670)
_cons	3.836*** (47.133)	3.465*** (44.105)	3.537*** (45.466)
Ind	YES	YES	YES
Year	YES	YES	YES
N	39844	39844	39844
Adj R <sup>2</sup>	0.713	0.644	0.457
F	1412.994	1031.187	480.907

#### 4.4.2 replacing sample periods and adding firm fixed effects

To ensure the reliability and unbiasedness of the baseline regression results, this study conducts robustness checks from two dimensions: sample period adjustment and fixed effects control. First, to exclude the potential influence of extreme external events on the estimation results, samples from the 2015 stock market crash and the COVID-19 pandemic in 2020 are removed. The regression results are presented in columns (1) and (2) of Table 8. The test results show that, after controlling for industry and year fixed effects, the coefficient of Corporate Social Responsibility (CSR1) on Total Factor Productivity (TFP) remains significantly positive at the 1% level, with a value slightly higher than that in the baseline regression. This indicates that the relationship between the core variables is not distorted by specific macroeconomic shocks.

Second, to control for time-invariant firm heterogeneity, this study introduces firm fixed effects, constructing a three-way fixed effects model. The empirical results in columns (3) and (4) show that the coefficient of CSR1 remains significantly positive after accounting for inherent firm characteristics. This confirms that the conclusions of the baseline regression are robust to potential omitted variable bias.

Table 8. Sample period replacement and addition of firm fixed effects

Variable name	(1)	(2)	(3)	(4)
	TFP_LP	TFP_OP	TFP_LP	TFP_OP
CSR1	0.287*** (18.509)	0.298*** (19.398)	0.103*** (8.740)	0.106*** (9.112)
Size	0.436*** (119.657)	0.107*** (29.645)	0.341*** (75.968)	0.010** (2.212)
Roa	3.073*** (48.229)	3.016*** (47.752)	2.069*** (53.558)	2.050*** (53.821)

Variable name	(1)	(2)	(3)	(4)
	TFP_LP	TFP_OP	TFP_LP	TFP_OP
Lev	1.384*** (61.249)	1.398*** (62.405)	0.754*** (37.863)	0.775*** (39.448)
Cash	-0.052 (-0.896)	0.009 (0.160)	0.427*** (12.379)	0.440*** (12.909)
Growth	-0.004 (-1.189)	-0.005 (-1.551)	0.005** (2.333)	0.004** (2.048)
Board	0.114*** (4.925)	0.142*** (6.207)	0.105*** (4.832)	0.109*** (5.077)
Indep	0.446*** (5.584)	0.522*** (6.591)	0.253*** (3.836)	0.260*** (4.009)
Top1	0.087*** (3.001)	0.074** (2.570)	-0.214*** (-6.229)	-0.218*** (-6.427)
Inst	0.422*** (22.582)	0.438*** (23.674)	0.510*** (22.632)	0.510*** (22.984)
Age	0.020 (1.550)	0.020 (1.615)	0.283*** (8.164)	0.297*** (8.699)
_cons	3.499*** (41.572)	3.570*** (42.799)	4.181*** (31.202)	4.311*** (32.626)
Ind	YES	YES	YES	YES
Year	YES	YES	YES	YES
ID	NO	NO	YES	YES
N	34137	34137	39844.000	39844.000
Adj R <sup>2</sup>	0.647	0.462	0.417	0.278
F	921.322	431.480	477.024	289.219

#### 4.4.3 Extending the observation window

This study tests robustness by extending the observation window through the introduction of lagged terms from 1 to 3 periods. As shown in columns (1) to (3) and columns (4) to (6) of Table 9, the coefficients of the core explanatory variable across multiple lagged periods remain significantly positive at least at the 1% level, confirming the robustness of the conclusions.

Table 9. Extending the observation period for robustness check

Variable name	(1)	(2)	(3)	(4)	(5)	(6)
	TFP_LP	TFP_LP	TFP_LP	TFP_OP	TFP_OP	TFP_OP
L1.CSR1	0.257*** (16.830)			0.269*** (17.807)		
L2.CSR1		0.232***			0.244***	

Variable name	(1)	(2)	(3)	(4)	(5)	(6)
	TFP_LP	TFP_LP	TFP_LP	TFP_OP	TFP_OP	TFP_OP
		(14.265)			(15.184)	
L3.CSR1			0.200*** (11.678)			0.212*** (12.554)
Size	0.443*** (121.147)	0.450*** (113.790)	0.455*** (107.060)	0.115*** (31.932)	0.123*** (31.431)	0.129*** (30.767)
Roa	2.976*** (48.051)	2.898*** (44.632)	2.826*** (41.447)	2.926*** (47.791)	2.851*** (44.490)	2.784*** (41.419)
Lev	1.381*** (60.754)	1.354*** (55.345)	1.322*** (50.241)	1.390*** (61.855)	1.359*** (56.287)	1.324*** (51.063)
Cash	0.137** (2.313)	0.148** (2.308)	0.194*** (2.806)	0.187*** (3.189)	0.196*** (3.096)	0.240*** (3.515)
Growth	-0.003 (-0.821)	-0.001 (-0.226)	0.001 (0.342)	-0.004 (-1.157)	-0.002 (-0.533)	0.000 (0.015)
Board	0.096*** (4.171)	0.077*** (3.103)	0.057** (2.110)	0.125*** (5.451)	0.105*** (4.282)	0.086*** (3.236)
Indep	0.432*** (5.436)	0.424*** (4.969)	0.410*** (4.479)	0.506*** (6.443)	0.501*** (5.949)	0.489*** (5.418)
Top1	0.049* (1.678)	0.035 (1.070)	0.036 (1.006)	0.035 (1.185)	0.019 (0.593)	0.020 (0.578)
Inst	0.440*** (22.886)	0.473*** (22.109)	0.489*** (20.488)	0.456*** (23.982)	0.488*** (23.112)	0.502*** (21.360)
Age	0.015 (1.135)	-0.005 (-0.298)	-0.018 (-1.014)	0.014 (1.011)	-0.007 (-0.483)	-0.021 (-1.198)
_cons	3.602*** (42.246)	3.635*** (39.127)	3.723*** (36.757)	3.677*** (43.623)	3.709*** (40.456)	3.793*** (37.990)
Ind	YES	YES	YES	YES	YES	YES
Year	YES	YES	YES	YES	YES	YES
N	34465	29926	26038	34465	29926	26038
Adj R <sup>2</sup>	0.647	0.647	0.645	0.463	0.464	0.461
F	930.158	820.777	718.053	438.039	388.055	338.513

#### 4.5 Heterogeneity analysis

This study examines the heterogeneous effects of corporate social responsibility (CSR) information disclosure on total factor productivity (TFP) from two dimensions: equity nature and audit quality. By constructing interaction term models, we delve into the differential manifestations of the economic consequences of CSR information disclosure under different institutional contexts and market conditions.

Columns (1) and (2) of Table 10 report the regression results grouped by equity nature. The coefficients of the interaction term CSR1SOE are both statistically significant under the two TFP measures (TFP\_LP and TFP\_OP), indicating that equity nature (whether a firm is state-owned or not) significantly moderates the impact of CSR on TFP, demonstrating significant heterogeneity. The coefficients for CSR1SOE are 0.270 and 0.278 under the two measures, respectively, both significantly positive at the 1% level. This suggests that the enhancing effect of CSR information disclosure on TFP is more pronounced in state-owned enterprises compared to non-state-owned enterprises.

Columns (3) and (4) of Table 10 present the moderating effect of audit quality on the CSR-TFP relationship. The coefficient of the interaction term CSR1×Big4 is significantly positive, indicating that the promoting effect of CSR information disclosure on TFP is stronger for companies audited by international "Big Four" accounting firms.

Table 10. Heterogeneity analysis

Variable name	(1)	(2)	(3)	(4)
	TFP_LP	TFP_OP	TFP_LP	TFP_OP
CSR1	0.180*** (10.415)	0.187*** (10.970)	0.245*** (16.804)	0.255*** (17.645)
SOE	-0.044*** (-3.026)	-0.039*** (-2.687)		
CSR1*SOE	0.270*** (10.192)	0.278*** (10.595)		
Big4			0.094** (2.460)	0.104*** (2.741)
CSR1*Big4			0.418*** (6.827)	0.432*** (7.127)
Size	0.433*** (128.033)	0.104*** (31.157)	0.422*** (123.780)	0.093*** (27.539)
Roa	3.114*** (53.165)	3.061*** (52.777)	3.103*** (53.279)	3.047*** (52.878)
Lev	1.387*** (66.039)	1.398*** (67.235)	1.409*** (67.670)	1.422*** (69.035)
Cash	0.040 (0.739)	0.098* (1.832)	-0.018 (-0.327)	0.037 (0.696)
Growth	-0.005 (-1.638)	-0.007** (-2.145)	-0.005 (-1.436)	-0.006* (-1.917)
Board	0.074*** (3.420)	0.098*** (4.576)	0.101*** (4.729)	0.128*** (6.067)
Indep	0.368*** (4.962)	0.435*** (5.924)	0.334*** (4.523)	0.401*** (5.495)
Top1	0.057** (2.109)	0.041 (1.551)	0.072*** (2.699)	0.058** (2.203)
Inst	0.374*** (20.990)	0.385*** (21.849)	0.370*** (21.330)	0.384*** (22.342)
Age	0.001 (0.121)	-0.001 (-0.051)	0.028** (2.395)	0.029** (2.466)
_cons	3.730*** (46.526)	3.823*** (48.164)	3.674*** (46.936)	3.757*** (48.511)
Ind	YES	YES	YES	YES
Year	YES	YES	YES	YES
N	39844	39844	39844	39844
Adj R <sup>2</sup>	0.647	0.462	0.650	0.468
F	1014.735	476.696	1029.818	487.675

## 5. Discussion

### 5.1 Summary of key findings

This study empirically examines the impact of corporate social responsibility (CSR) disclosure on total factor productivity (TFP) using a large-sample dataset of Chinese A-share listed companies from 2010 to 2023. The baseline regression results robustly demonstrate that high-quality CSR disclosure significantly enhances TFP, as measured by both the LP and OP methods. Mechanism tests reveal that CSR disclosure improves TFP through dual pathways: the resource aggregation effect (e.g., alleviating financing constraints and optimizing human capital structure) and the supervisory governance effect (e.g., enhancing media attention and internal control quality). Furthermore, heterogeneity analysis indicates that the positive impact of CSR disclosure on TFP is more pronounced in state-owned enterprises and firms audited by Big Four accounting firms.

### 5.2 Theoretical implications

First, this study extends the application of stakeholder theory and signaling theory by integrating TFP as a core indicator of operational efficiency. While prior literature predominantly links CSR to financial performance, our findings highlight that CSR disclosure serves as a critical tool for optimizing resource allocation and productivity, aligning corporate sustainability practices with long-term operational efficiency.

Second, the validated dual-pathway mechanism (resource aggregation and supervisory governance) refines the understanding of how CSR translates into economic value. For instance, the mediation effect of financing constraints underscores the role of CSR in mitigating information asymmetry and reducing capital costs, while the human capital channel emphasizes CSR's function in attracting talent and enhancing innovation capacity. These findings bridge CSR research with productivity theory, offering a micro-foundation for sustainable development strategies.

Third, the heterogeneity results underscore the contextual dependence of CSR's effectiveness. The stronger TFP improvement in state-owned enterprises reflects the synergy between CSR and China's institutional environment, where SOEs face higher expectations for social responsibility fulfillment. Similarly, the moderating role of Big Four audits reinforces the importance of external governance in amplifying CSR's credibility and impact.

### 5.3 Practical and policy implications

For enterprises, our results suggest that proactively disclosing high-quality CSR information is not merely a regulatory compliance task but a strategic investment to boost productivity. Managers should leverage CSR disclosure to strengthen investor confidence, optimize human capital, and improve internal governance systems.

For policymakers, this study supports the enforcement of CSR disclosure mandates as a viable policy tool to promote sustainable economic growth. Regulatory bodies could refine disclosure guidelines to encourage standardized, transparent CSR reporting, particularly for industries with high environmental or social impacts. Additionally, incentives (e.g., tax benefits or credit support) could be designed to reward firms that demonstrate tangible productivity gains through CSR practices.

For investors and stakeholders, the findings provide evidence that CSR disclosure quality can serve as a signal of a firm's operational efficiency and long-term resilience, aiding investment decisions and stakeholder engagement.

### 5.4 Limitations and future research

This study has several limitations. First, the sample focuses on Chinese listed companies, which may limit the generalizability of findings to other economies with distinct institutional contexts. Future research could conduct cross-country comparisons to explore institutional moderators. Second, while we tested four mediation channels, other potential mechanisms (e.g., supply chain collaboration or technological innovation networks) warrant investigation. Third, the study primarily uses structured CSR metrics; qualitative aspects of disclosure (e.g., narrative tone or visual elements) could be examined using natural language processing methods.

Finally, as global attention to ESG (environmental, social, and governance) criteria grows, future work could extend our framework to explore the differential impacts of environmental versus social disclosure on green TFP or analyze how digital transformation moderates the CSR-TFP relationship.



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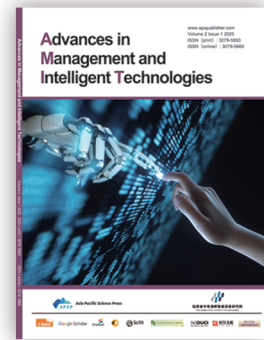


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