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Advances in Management and Intelligent Technologies

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Table of Contents

- 1 Evaluation of Ningxia Gojiberry Traceability System Construction and Analysis of Its Driving Factors**
Jiapeng Zhao, Yu Li, Yaqin Ma, Zhiqi Xu, Shidai Li
- 6 The Impact of Behavioral Economics on Consumer Decision-Making in the Digital Era**
Yixin Chen
- 15 Research on the Role of Digital Economy in Promoting Rural Revitalization: A Study from the Perspective of Industrial Agglomeration**
Yixin Chen, Weihua Sun
- 29 Problems of Lagging Brand Building of Agricultural Products Affecting Market Competitiveness and Countermeasures of Traceability System**
Runqi Chen, Xinyong Lu
- 35 Strategic Construction of the Technology Ecosystem in the Healthcare Industry: Synergistic Optimization of Innovation Policy, Organizational Agility and Talent Pool**
Chung Muhui, Oyyappan Duraipandi, Dhakir Abbas Ali, Rozaini Rosli
- 41 Research on the Synergistic Mechanism of Strategic Innovation and Technological Progress —— An Empirical Analysis Based on the Organizational Performance of the Medical Industry**
Chung Muhui, Oyyappan Duraipandi, Dhakir Abbas Ali, Rozaini Rosli
- 47 Digital Protection and Inheritance: the Modern Way of Protecting Cangyuan Rock Painting**
Liu Qianyu, Muhammad Fadhil Wong Bin Abdullah
- 53 Inventory Optimization in Retail Supply Chains Using Deep Reinforcement Learning**
Min-Jae Park, Olivia Turner, Thomas Becker
- 60 Optimizing Discount Allocation with Deep Learning in Competitive Markets**
Lei Tang, Ning Zhou

- 67 Technical Implementation of Large Language Models in Educational Scenarios: A Case Study of DeepSeek**

Pengfei Zhao, Xin Wan

- 76 The Influence of the Travel Motivation and Destination Image on the Tourism Intention of Retired Immigrants**

Yining Zhao, Xi He

Evaluation of Ningxia Gojiberry Traceability System Construction and Analysis of Its Driving Factors

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Abstract: Building a comprehensive Gojiberry traceability system is a key measure to enhance the quality and safety of Ningxia's authentic medicinal materials. This study constructs an evaluation system from four dimensions: "technical support, information coverage, quality assurance, and market benefits," uses the entropy method to measure the traceability construction level in Ningxia's main Gojiberry production areas from 2021 to 2024, and employs the geographic detector to analyze driving mechanisms. The research shows that the comprehensive index of Ningxia's Gojiberry traceability system grew at an annual average rate of 12.3%, with Zhongning County leading in construction level. Policy support ($q=0.682$) and IoT technology penetration ($q=0.573$) are the primary driving factors, and the interaction between leading enterprise participation and environmental regulation ($q=0.84$) is significant. It is recommended to strengthen government-enterprise collaborative innovation and establish a "blockchain + base certification" dual-driven model^[1].

Keywords: Gojiberry Industry; Traceability System; Geographic Detector; Quality and Safety; Ningxia

Published: May 26, 2025

DOI: <https://doi.org/10.62177/amit.v1i3.390>

1.Introduction

1.1 Data Sources

Ningxia Gojiberry, as a national geographical indication product, accounts for 70% of the transaction volume of Gojiberry nationwide (Chinese Medicinal Materials Association, 2023). However, the frequent quality incidents in recent years have threatened its international reputation: nine of the 12 batches of Gojiberry returned by the European Union in 2022 were produced in Ningxia, and the main problems were the excessive pesticide residues (the content of thiamethoxam exceeded the European Union standard by 3.8 times) and the counterfeiting of origin^[2].

1.2 Policy Requirements and Practical challenges

The national genuine medicinal material production base construction plan (2018-2025) clearly requires that the traceability system should be fully covered by 2025. However, three major contradictions were exposed in the actual promotion:

Technical contradiction: the existing blockchain system processes 200000 pieces of data per day, but the annual output of Gojiberry in Ningxia needs to process 120million pieces

Cost contradiction: small farmers need to bear the cost of 782 yuan/mu for installing traceability equipment, equivalent to 18% of annual income^[3].

Standard contradiction: among the current 34 domestic testing standards, only 17 overlap with the European Union.

1.3 Research Gaps and Breakthrough Directions

Technology application disconnection: the precision of the intelligent sensor laboratory developed by Wang Jing's team (2021) reached 99.2%, but the actual use error in the field exceeded 15%^[4].

Academic industry disconnection: of the 128 relevant papers in the past five years, only 6 used real data from enterprises

Regional global disconnection: the existing evaluation model does not consider the unique three-level production structure of "enterprises+cooperatives+farmers" in Northwest China

1.4 research value and Practice Path

This study solves the dilemma through three innovations:

Build a dynamic evaluation model: integrate the panel data of 12 major production counties from 2018 to 2023, covering 7 key nodes of the whole industry chain.

Reveal the hidden cost structure: it is estimated for the first time that the hidden cost of the traceability system accounts for 43% of the total investment (mainly data maintenance and personnel training)^[5].

Establish a standard convergence mechanism: design a comparison table for the transformation of 62 test indicators covering the European and European standards.

2. Research Design

2.1 Data Sources

Data were collected through three channels:

2.1.1 Government Reports (2018–2022)

Annual Gojiberry Quality and Safety Monitoring Reports issued by the Ningxia Department of Agriculture and Rural Affairs (covering 12 major production counties)^[6].

Gojiberry inspection reports downloaded from the official website of the State Administration for Market Regulation (focusing on pesticide residue data).

2.1.2 Enterprise Collaboration

QR code traceability records of Gojiberry products provided by e-commerce platforms (e.g., JD.com and Tmall), totaling 5,763 entries.

Equipment installation ledgers of enterprises provided by the Zhongning Gojiberry Industry Association.

2.1.3 Field Surveys

986 valid questionnaires collected from five evaluation regions during July–August 2024.

Interviews with 12 cooperative managers and 5 industry experts.

2.2 Indicator Selection Methodology

Referencing China's Agricultural Product Traceability Management Standards, we selected evaluation indicators from four dimensions.

Referencing the national Agricultural Product Traceability Management Standards, we established indicators across four dimensions (Table 1):

Table 1. Evaluation Indicator System

Dimension	Specific Indicators	Evaluation Basis
Technical Infrastructure	IoT devices per 10,000 mu	Reflects data collection capacity
	Blockchain coverage in processing factories	Ensures data immutability
Information Transparency	Full-process data completeness	Consumer-focused traceability requirement
	QR code scan success rate	Field-tested performance metric

Dimension	Specific Indicators	Evaluation Basis
Quality Assurance	Pesticide compliance rate	National inspection standard
	Organic certification base ratio	High-end market competitiveness
Market Performance	Price premium for traceable products	Comparative analysis via Taobao
	Repurchase rate increase	Consumer trust indicator

Weight calculation via entropy method:

Pesticide compliance rate received higher weight (0.176) than organic certification (0.154), emphasizing safety fundamentals over premium certifications^[7].

3. Empirical Analysis

3.1 Data Preprocessing and Validation

Data sources: Panel data from 10 main production counties (Ningxia Forestry and Grassland Bureau, 2020-2024)

Reliability: Cronbach's $\alpha = 0.872$; Split-half reliability = 0.811

Validity: KMO = 0.793; Bartlett's $\chi^2 = 1,253.7$ ($p < 0.001$)

Confirmatory Factor Analysis: RMSEA = 0.048; CFI = 0.937; TLI = 0.921

3.2 Entropy Method Implementation

3.2.1 Standardization processing

Using the range method to eliminate dimensions, perform reciprocal processing on negative indicators (such as pesticide residue exceedance rate):

$$x'_{ij} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)} \text{ (positive indicators)}$$

$$x'_{ij} = \frac{\max(x_j) - x_{ij}}{\max(x_j) - \min(x_j)} \text{ (negative indicators)}$$

3.2.2 Weight Calculation

Calculate the information entropy of the j th indicator:

$$e_j = -\frac{1}{\ln n} \sum_{i=1}^n p_{ij} \ln p_{ij}$$

Weight determination:

$$w_j = \frac{1 - e_j}{\sum_{j=1}^m (1 - e_j)}$$

3.2.3 Robustness

Bootstrap resampling (1,000 iterations) confirmed stability (e.g., blockchain coverage weight 95% CI [0.201, 0.225]).

3.3 Regional Driving Factors

Policy investment \times leading enterprise participation: $q = 0.84$ (enhanced interaction)

IoT density \times accumulated temperature: $q = 0.79$ (nonlinear enhancement)

Spatial heterogeneity: Policy effect stronger in Zhongning ($\beta = 0.372$, $p < 0.01$) than Hongsipu ($\beta = 0.154$, $p > 0.1$)

3.4 Dynamic Panel Regression (System GMM)

Model:

$$Y_{it} = \alpha + \beta_1 \text{Policy}_{it} + \beta_2 \text{Tech}_{it} + \beta_3 \text{Market}_{it} + \beta_4 X_{it} + \mu_i + \varepsilon_{it}$$

Significant Results:

Policy support shows short-term elasticity 0.217 ($t = 3.21^{**}$) and long-term cumulative effect 0.398.

IoT density increase by 1 unit boosts traceability efficiency by 0.184 (95% CI [0.112, 0.256]).

Consumer complaints exhibit inverted-U impact on market performance (inflection point: 2.35 complaints/10k orders).

4. Conclusions and Recommendations

4.1 Key Findings

“Last mile” obstacle in technology landing. Case comparison: 83% of the processing plants in Zhongning County deploy the blockchain system, but the Internet of things coverage at the planting end is only 29% (see Figure 2). Just as the city has built expressways, the countryside lacks connecting roads.

Equipment dilemma: field tests in 2023 showed that 37% of sensors failed due to sand and dust intrusion, and 23% of equipment was damaged due to misoperation by farmers (data source: field monitoring log of the research group).

There is a “sandwich fault” in the data chain. Lack of processing links: 61% of the enterprises did not upload the *Lycium barbarum* cleaning and drying process parameters (if the temperature fluctuation exceeds $\pm 5^{\circ}\text{C}$, the efficacy will be affected).

Human intervention vulnerability: in 2022, an enterprise tampered with 2300 detection records, and the premium of falsely labeled organic certified products reached 42% (Punishment Notice of the State Administration of market supervision).

Cost sharing falls into “small farmers’ dilemma”. Direct cost: it costs 782 yuan/mu to install traceability equipment, equivalent to 18% of the annual income of small farmers (Ningxia University survey in 2023). Hidden cost: farmers need to spend an additional 47 minutes to operate equipment every day, resulting in 32% of participants giving up halfway (tracking data of the research group).

The standard system faces “double mismatch”. Differences at home and abroad: among the current 34 detection indicators in China, only 17 are completely consistent with the EU. For example, the residue standard of thiamethoxam is 0.5mg/kg in China and 0.05mg/kg in the European Union. Dynamic lag: in the new edition of Chinese pharmacopoeia in 2024, five new detection indicators were added, but 35% of the existing equipment could not support the detection of new parameters.

Market reaction presents “trust threshold”^[8]. When traceability products account for more than 75%, consumers are willing to pay more. Just like only half of the apples in the supermarket are labeled, customers will doubt whether there is a problem with what is not labeled. Tmall data confirmed that after a brand in Zhongning reached 82% coverage, the repurchase rate soared from 31% to 58%.

4.2 Practical Suggestions

Technological innovation: make the equipment “smart and solid”. Fool terminal: develop farmer specific equipment with no more than 3 keys (refer to the design logic of elderly mobile phones). The test shows that the operation error rate can be reduced from 47% to 12%. Stress resistance Transformation: the equipment is equipped with dust-proof filter screen (the cost is increased by 8 yuan/set) and solar panel (the average daily power generation is 0.3kwh, meeting the data transmission demand).

Policy Optimization: use funds on the cutting edge. Precision subsidies: the model of “equipment leasing+rewards instead of subsidies” was implemented for small and micro farmers under 20 mu, and the participation rate in the pilot areas increased from 31% to 79%. Process audit: introduce the blockchain audit system to automatically verify the online rate of equipment (need to be >85%), data integrity (need to be >90%) and other indicators before allocating subsidies.

Market driven: let good products sell at a good price. Premium classification: a three-level price system of “basic traceability (+5%) - organic certification (+15%) - EU standard (+25%)” was established, and the repurchase rate of a brand in Zhongning increased by 27%. Insurance: set up a special insurance fund. Consumers who scan the code and find quality problems can get 10 times the compensation. The fund is shared by the government and leading enterprises in the proportion of 7:3^[9].

Standard connection: Build International Bridges. Dynamic conversion table: develop the intelligent conversion system of China EU standards, input the domestic detection value to automatically generate the EU compliance report, and shorten the enterprise export certification cycle from 43 days to 9 days. Early warning radar: establish a monitoring network for changes in standards in 120 major markets around the world, and successfully warn Japan to modify sweetener standards in 2023 to avoid a loss of 6.5 million yuan.

4.3 Critical Considerations

Data authenticity: Third-party audits to prevent IoT malfunction-induced “data bubbles.”

Smallholder inclusion: Mini-traceability kits for 20-mu micro-farms (78% of growers).

Regulatory alignment: Synchronize equipment upgrades with 2024 pesticide standard updates^[10].

Funding

2024 Ningxia Hui Autonomous Region Youth Science and Technology Support Talent Training Project

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 Behavioral Economics on Consumer Decision-Making in the Digital Era

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Abstract: With the rapid development of digital technologies, the consumer decision-making process has undergone significant changes in the digital environment. This paper, from the perspective of behavioral economics, explores the irrational characteristics of consumer decision-making in the digital era and the underlying psychological mechanisms. The study shows that digital technologies such as information overload, personalized recommendations, social media group effects, and digital payments not only profoundly influence consumer choices but also exacerbate the manifestation of behavioral economic phenomena such as bounded rationality and mental accounting. By analyzing key concepts in behavioral economics, such as reference dependence and loss aversion, the paper reveals how consumers make “good enough” decisions rather than optimal ones on digital platforms. Finally, the paper offers policy recommendations and practical insights aimed at providing theoretical support for the healthy development of digital marketing and the digital economy.

Keyword: Behavioral Economics; Consumer Decision-Making; Digital Technology; Information Overload; Personalized Recommendations; Marketing Strategies

Published: May 26, 2025

DOI: <https://doi.org/10.62177/amit.v1i3.391>

1.Introduction

1.1 Research Background

In the context of digital transformation, the decision-making process of modern consumers has undergone profound changes. Technological innovations, particularly the widespread application of artificial intelligence, big data, digital payments, and intelligent recommendation systems, have not only altered the way consumers make purchases but also influenced their thinking and behavioral patterns. In traditional economics, consumers are typically viewed as rational decision-makers who make optimal choices based on complete information^[1]. However, in the digital age, factors such as information overload, virtual social influence, and instant purchasing make the decision-making process more complex and dynamic. In particular, the use of personalized advertising and recommendation algorithms means that consumers' choices are often influenced by implicit factors and emotional drives, which are not fully accounted for in traditional economic theories.

Digital tools, such as social media platforms, smart recommendation engines, and mobile payment systems, are fundamentally reshaping consumer purchasing behavior. These technologies not only make it easier to access product information but also alter the decision-making paths of consumers^[2]. In this process, consumer choices become increasingly reliant on external behavioral cues and instant feedback, rather than solely relying on personal experience or market prices.

Behavioral economics provides a new perspective for analyzing how these external factors impact the consumer decision-making process.

1.2 Research Questions

This paper will explore the following key questions:

Which theories from behavioral economics can effectively explain the changes in consumer decision-making in the digital environment?

How are consumer decisions influenced by new digital tools, platforms, and information technologies (such as personalized advertising, social media, artificial intelligence, etc.)?

In the digital age, how do behavioral biases and psychological factors play a role in consumer decision-making?

1.3 Research Objectives and Significance

The aim of this study is to explore how key concepts from behavioral economics influence consumer behavior in the digital age. By analyzing how digital tools alter consumer decision-making paths, this paper provides not only a deeper understanding of consumer behavior in the digital era but also a theoretical basis for policymakers and business strategists^[3]. Particularly in areas such as marketing, consumer protection, and digital payments, understanding the complexities of consumer decisions in the digital environment will help formulate more effective policies and business strategies, ultimately improving consumer service and enhancing corporate competitiveness.

2. Literature Review

2.1 Fundamental Theories of Behavioral Economics

2.1.1 Bounded Rationality

Traditional economics assumes that consumers are perfectly rational decision-makers who can analyze all available information and make optimal choices. However, Herbert Simon's theory of bounded rationality suggests that, when facing complex decisions, consumers are often unable to obtain complete information or perform comprehensive cost-benefit analyses. As a result, the decisions they make are often "good enough" rather than optimal^[4]. In the digital age, consumers are confronted with information overload and time constraints, making the concept of bounded rationality especially important for explaining consumer behavior in digital environments. On digital platforms, consumers often cannot make the best choice due to the diversity and complexity of information. They tend to rely on simplified decision rules, such as selecting platform-recommended products or directly clicking on promotional ads, instead of thoroughly analyzing all options available.

2.1.2 Mental Accounting

Richard Thaler's mental accounting theory suggests that consumers categorize wealth and spending into different mental accounts, which influences their consumption decisions. For example, consumers may separate everyday expenses from luxury purchases, and this "accounting" mentality leads them to apply different rational standards to various types of expenditures^[5]. With the proliferation of digital payments and online shopping, consumer spending has become more fragmented and irrational. On e-commerce platforms, consumers may focus on a specific promotion or shopping coupon while disregarding their overall financial situation.

2.1.3 Reference Dependence

The theory of reference dependence posits that consumer decisions are influenced not only by absolute prices but also by the relative position of prices (reference points). In the digital environment, price comparison tools, discount labels, and coupon mechanisms on platforms have altered consumers' reference points, changing their perception of prices. Through promotional activities such as time-limited discounts and flash sales, consumers tend to make purchase decisions based on these reference points, disregarding the actual value of the products or their own consumption needs. This phenomenon is particularly prevalent on digital platforms, where consumers are more easily swayed by short-term offers due to multi-platform price comparisons and social media recommendations.

2.1.4 Default Effect

The default effect refers to the tendency of consumers to accept the default option when faced with a choice, rather than making an active decision. On digital platforms, especially in the design of auto-renewals, subscription services, and digital

payment tools, default settings play a crucial role. For example, many online platforms automatically set subscription options to auto-renew, and consumers often overlook this setting, leading to unnecessary renewal fees^[6]. Digital platforms can optimize default option designs to boost sales or extend the consumer lifecycle without interfering with the user's decision-making process.

2.1.5 Loss Aversion

Loss aversion theory suggests that people feel losses more intensely than equivalent gains. On e-commerce platforms, limited-time promotions, coupon usage, and limited-quantity sales strategies exploit this psychological mechanism, driving consumers to make impulsive purchases to avoid missing out on discounts or opportunities. Digital platforms stimulate consumers' desire to purchase by using countdown promotions and displaying "only a few left" notifications, leveraging the loss aversion mindset to speed up the decision-making process.

2.2 Consumer Behavior in the Digital Age

2.2.1 Changes in Information Flow

Traditional shopping methods mainly relied on advertising, store displays, and word-of-mouth recommendations. In the digital age, social media, e-commerce platforms, and search engines provide real-time information flow channels. Consumers can easily access product reviews, price comparisons, and brand stories, which makes their decisions more diverse and complex. Through these platforms, consumers can quickly acquire various opinions and recommendations about products, which influences their purchase intentions^[7].

2.2.2 Diversification of Market Choices

The rise of digital platforms has given consumers unprecedented choice space. Through e-commerce platforms, consumers can access goods and services from around the world, thus breaking the geographical and physical limitations of traditional markets. This change not only increases consumers' freedom of choice but also leads to decision fatigue and delay. Faced with numerous products and brands, consumers often rely on platform recommendations or other people's reviews to simplify their decision-making process, which may result in irrational decisions.

2.2.3 Speed and Impulsiveness in Purchase Decisions

With the widespread use of mobile payments and instant purchase features, consumer purchase decisions have become faster and more impulsive. On digital platforms, consumers can easily make purchases without much deliberation. This phenomenon is partly due to psychological incentives embedded in platform designs, such as time-limited discounts, instant offers, and personalized recommendations, which exploit consumers' loss aversion and reference dependence. While this rapid purchasing behavior may increase short-term sales, it can also lead consumers to make irrational decisions without adequate consideration.

2.3 The Integration of Behavioral Economics and Digital Technology

2.3.1 Algorithmic Recommendations and Personalized Advertising

Big data and artificial intelligence technologies enable platforms to push personalized advertisements and recommendations based on users' historical behavior, preferences, and social network information. Behavioral economics theories such as reference dependence and loss aversion help explain why users are more likely to accept recommendations that align with their past behavior and ignore other potential choices. For example, platforms collect and analyze user data to predict future consumption needs and conduct targeted marketing based on these predictions.

2.3.2 Data-Driven Marketing Strategies

On digital platforms, companies can analyze large amounts of consumer behavior data to accurately predict user needs and implement corresponding market strategies. Behavioral economics theories like the "default effect" and "loss aversion" can be used to design more effective promotional activities, such as setting default subscription options, offering time-limited discounts, and providing coupons to prompt consumers to make quick purchasing decisions. These strategies not only increase sales but also accelerate the consumer decision-making process, reducing decision time.

2.3.3 Social Media and Collective Decision-Making

The popularity of social media means that consumers are increasingly influenced by social factors in their decision-making.

The “bandwagon effect” in behavioral economics explains how group behavior on social media affects individual decisions. On e-commerce platforms, user reviews, likes, and social recommendations serve as social proof, encouraging consumers to make purchase decisions in situations where they lack complete information. Social media’s “collective wisdom” leads consumers to mimic others’ purchasing choices, thereby influencing their decision-making process.

2.4 Existing Research Gaps

2.4.1 Limited Behavioral Economic Explanations on Digital Platforms

Although existing research has explored the impact of digital technologies on consumer behavior, there is still a lack of behavioral economic explanations on digital platforms, especially e-commerce and social media platforms. Specifically, how behavioral economics theories can help understand consumers’ decision biases and irrational behaviors on these platforms remains an underexplored area.

2.4.2 Limitations of Laboratory-Based Studies

Much of behavioral economics research relies on controlled laboratory experiments, which limits the applicability of its conclusions in real-world settings. As digital platforms diversify, the real-world scenarios of consumer behavior become more complex, and traditional laboratory research may not fully reflect the consumption behavior in actual environments. Therefore, future studies need to adopt big data analysis methods and actual platform data to obtain more realistic and reliable conclusions.

2.4.3 Lack of Long-Term Impact Studies in Digital Environments

Currently, most studies focus on short-term changes in consumer behavior, with relatively little research on long-term impacts. The long-term effects of promotional activities, algorithmic recommendations, and other factors on digital platforms have not been thoroughly explored. Future research should focus on the role of these behavioral economic mechanisms in long-term consumer decision-making.

3. Theoretical Framework

3.1 Bounded Rationality and Digital Information Overload

In the digital age, information overload is one of the major challenges consumers face. Consumers access large amounts of product information, advertisements, reviews, recommendations, and other content through digital platforms. While this information helps in decision-making, it can also lead to “choice fatigue” or information anxiety, affecting the quality of their decisions. According to the theory of bounded rationality, when confronted with such a vast amount of information, consumers are often unable to conduct a comprehensive analysis and comparison. Therefore, they rely on simplified decision rules to cope with complex choice tasks. For example, when faced with multiple product or service options, consumers may reduce their decision burden by selecting platform-recommended items, default options, or filtering conditions, thus making a “good enough” decision rather than an optimal one. Additionally, default options in platform design (such as automatic subscriptions or renewals) reduce decision complexity, allowing consumers to make purchase decisions without much further thought.

3.2 Mental Accounting and Digital Payments

Mental accounting theory suggests that consumers categorize their funds into different accounts based on their purposes and sources, which affects their spending behavior. In the context of digital payments, consumers create a virtual “invisible money” effect through digital wallets, credit card payments, and other methods, which impacts their consumption decisions. Compared to traditional cash payments, digital payments lead consumers to experience a psychological separation from the expense, making it harder for them to feel the immediacy of spending or the actual loss. As a result, they are more likely to engage in impulsive spending behaviors. This phenomenon occurs because digital payments detach the immediate pain of payment from the transaction, making consumers more likely to overspend or make hasty purchasing decisions.

3.3 Reference Dependence and Pricing Strategies

Reference dependence theory emphasizes that consumer decisions are not only influenced by the inherent value of a product but also by the reference point (or benchmark) set for comparison. Digital platforms leverage various strategies to guide consumer purchasing decisions using reference effects. On e-commerce platforms, consumers often compare the price of

a product with a reference price, which could be the original price, discounted price, or prices of similar products on the market. Therefore, e-commerce platforms frequently use tactics like showing “original price,” “current price,” and “discounted price” to influence consumers’ perception of the price. These strategies aim to make consumers feel they are receiving a better deal, even if the actual product value does not warrant such a purchase.

3.4 Loss Aversion and Personalized Advertising

Loss aversion is a core concept in behavioral economics, which suggests that people are more sensitive to losses than to gains of equal value. In the digital age, the combination of loss aversion psychology with personalized advertising strategies leads consumers to develop a strong desire to make purchases. Platforms conduct precise data analysis based on consumers’ browsing history, purchase records, and social media behavior to push personalized ads, triggering the fear of “missing out” on an opportunity.

For instance, e-commerce platforms frequently use strategies such as “limited-time flash sales,” “only one left,” or “countdown promotions” to activate loss aversion in consumers, stimulating their desire to buy. In this scenario, consumers are often pushed to make decisions without sufficient information to avoid losing a discount or special offer.

4.Impact of Digital Technology on Consumer Decision-Making

4.1 Personalized Recommendation Systems

In the digital age, personalized recommendation systems have become crucial tools that influence consumer decision-making. By utilizing big data analytics and artificial intelligence, platforms can predict consumer needs and offer tailored product or service recommendations based on their past behaviors, browsing history, and social interactions. The implementation of personalized recommendations not only enhances the user experience but also reduces information overload and simplifies the decision-making process, thereby promoting purchase decisions.

These systems continuously adjust the recommendation content through algorithms to maximize consumer satisfaction and platform revenue. For example, e-commerce platforms display product recommendations such as “You might also like,” “Related products,” or “Combo deals” based on previous purchases or behaviors of similar consumers. This approach reduces the cost of information search, increases decision efficiency, and often makes consumers feel that the recommended content better fits their needs, thus increasing the likelihood of purchase. However, while personalized recommendations can boost platform conversion rates, they may also limit consumer choice freedom, making consumers more likely to engage in familiar consumption patterns while missing out on potentially valuable alternatives.

4.2 Social Media and Social Influence

Social media platforms have become significant channels that influence consumer decision-making, especially through behavioral economics phenomena like social influence, word-of-mouth, and social comparison. Consumers receive opinions, recommendations, and reviews of products and services from friends, celebrities, experts, and brands on social media. This interaction not only alters consumer purchase decisions but also amplifies the spread of information within social networks, creating a collective influence.

Reviews, recommendations, and sharing behavior on social media significantly enhance the social proof effect, with consumers tending to select products that have received good reviews or are widely shared. According to social influence theory, when a consumer sees that friends or peers have purchased and recommended a product, they are more likely to believe in its value, often disregarding other potential choices. This phenomenon is evident not only in B2C (business-to-consumer) markets but also in C2C (consumer-to-consumer) interactions, such as through social e-commerce or sharing economy platforms, where consumer purchase decisions are strongly influenced by group opinions.

4.3 Digital Payments and the Psychology of Payment Behavior

The widespread use of digital payment technologies has significantly changed consumer payment behavior. Unlike traditional cash payments, digital payments offer more convenient and anonymous payment methods, altering consumers’ perception of spending. When using credit cards, e-wallets, or mobile payments, consumers do not physically see the flow of cash, creating a “money invisibility” effect, which reduces the psychological cost of payment and leads consumers to make more impulsive decisions while shopping.

The convenience of digital payments promotes rapid consumption and frequent small payments, behaviors that often do not trigger immediate financial awareness in consumers. Research shows that consumers, when using digital payments, tend to overlook the immediacy of payments, resulting in budget overruns or unnecessary expenditures. Additionally, digital payment systems encourage further consumption by offering incentives like loyalty points, rewards, and coupons. Especially on e-commerce platforms, consumers often receive instant feedback (such as discounts, points, or special offers) at the time of payment, which increases their sense of immediate gratification and promotes more consumer spending.

Consumers' preferences for payment methods also influence their decision-making process. Many consumers tend to choose convenient and fast payment options, such as QR code payments or mobile payments, which reduce friction during the payment process and enhance the smoothness of the shopping experience, further affecting the speed and frequency of purchase decisions.

4.4 Virtual Reality and Immersive Shopping Experiences

Virtual Reality (VR) and Augmented Reality (AR) technologies are providing consumers with entirely new shopping experiences. These technologies create immersive shopping environments, allowing consumers to experience products or services in virtual worlds, which alters their emotional decisions and purchasing behavior. In virtual stores, consumers can not only view products from a 3D perspective to understand their appearance and features but also simulate usage scenarios to perceive the actual effects of products. This immersive experience breaks the limitations of traditional shopping, enhancing consumers' interest and emotional connection with products, thereby influencing their purchasing decisions.

Virtual reality also creates fully immersive virtual shopping environments, allowing consumers to feel as if they are physically entering a store, viewing products, trying items, or interacting with virtual sales staff or other consumers. This type of shopping not only increases consumer engagement and enjoyment but also boosts the desire to purchase by enhancing interactivity and entertainment. Through these immersive technologies, consumers can have more engaging and personalized shopping experiences, which in turn drives purchasing behavior.

5. Implications for Marketing Strategies

5.1 Pricing Strategies and Behavioral Economics

Behavioral economics offers rich theoretical insights for designing pricing strategies. While traditional economics assumes consumers have perfect rationality in price decisions, behavioral economics suggests that consumer pricing decisions are often influenced by psychological biases, which companies can leverage to create more attractive pricing strategies. Below are some common behavioral economics pricing strategies and their applications:

Anchoring Effect: The anchoring effect refers to the influence that initial information (the "anchor") has on consumer price decisions, often leading to biased judgments. Companies can use a high-priced "anchor" to make subsequent lower prices seem more attractive. For example, e-commerce platforms often display both the original price and the discounted price, making consumers believe they are getting a better deal and thus increasing their desire to purchase.

Tiered Pricing: By designing products or services at different levels (e.g., basic, premium, and elite versions), companies can use consumers' comparative psychology to encourage the purchase of higher-value products. By offering multiple price options, companies can meet the needs of different consumers and guide them toward higher-priced versions. The "reference effect" from behavioral economics plays a key role here, as consumers will judge the fairness of a price based on the reference prices provided, influencing their purchasing decisions.

Price Endings: Research shows that consumers have a strong preference for prices ending in .99 or .95, even though these prices differ little from whole numbers. This effect, known as the "left digit effect," means consumers pay more attention to the first digit of a price. Many companies adopt this pricing strategy to make products seem more appealing.

5.2 Personalized Marketing and Consumer Behavior Prediction

With the rapid development of big data technology, personalized marketing has become a key tool in modern marketing. By analyzing consumer behavior data, such as past behaviors, preferences, and social interactions, personalized marketing tailors products and service recommendations to each consumer. Behavioral economics plays a crucial role in personalized marketing by helping businesses more accurately predict consumer needs and behaviors.

Leveraging Mental Accounting: Behavioral economics' mental accounting theory reveals how consumers treat funds and spending in different contexts. Personalized marketing can utilize this by offering customized coupons, rewards, or incentives, encouraging consumers to spend more within specific accounts. For instance, platforms can provide personalized discounts or exclusive offers based on consumers' shopping histories, enhancing their purchasing intent.

Utilizing Loss Aversion: Loss aversion refers to the tendency of consumers to feel a stronger negative emotional reaction to losses than to equivalent gains. Businesses can use this psychological phenomenon by launching "limited-time offers" or "last-chance deals" to encourage consumers to make quick purchasing decisions. These strategies exploit consumers' excessive reactions to potential losses, sparking increased purchase desires.

Behavior-Driven Recommendation Systems: Using behavioral economics-based predictive models, companies can precisely capture consumers' potential needs. By analyzing consumers' online search behaviors, browsing history, and click frequency, personalized recommendation systems can suggest products or services consumers are most likely to be interested in. This precise marketing strategy can significantly improve conversion rates and customer loyalty.

5.3 Social Proof and Influencer Marketing

Social proof theory suggests that consumers often make decisions based on the behavior of others, especially when facing uncertainty or incomplete information. With the rapid growth of social media and online platforms, the role of social proof in marketing has become increasingly important. Companies can shape social influence and use consumer group behaviors to drive effective marketing.

User Reviews and Ratings: On online shopping platforms, user reviews, ratings, and feedback have become important reference points in consumer decision-making. Behavioral economics shows that consumers tend to choose products with higher ratings or positive reviews. This "group consensus" makes it easier for a company's product to attract new customers. Companies can actively manage and guide user reviews to shape social proof effects, thereby enhancing their brand's credibility and appeal.

Influencer and Social Media Influence: The influencer effect is a powerful form of social proof. Many companies now collaborate with well-known bloggers, social media personalities, or thought leaders to promote their products. Consumers often view an influencer's endorsement as a trustworthy social proof, which leads to imitation behavior. This influencer marketing not only increases product visibility but also boosts brand awareness and purchase desire.

"Social Recommendations" and Sharing Economy: Companies can also encourage consumers to recommend and share products, further expanding the social proof effect. For instance, by offering "share discounts" or "referral rewards" on social media, businesses can motivate existing customers to introduce new ones, leveraging consumers' social circles to influence more potential buyers.

6.Challenges and Future Directions

6.1 Ethical Issues in Digital Technology

With the rapid advancement of digital technology, changes in consumer behavior are not only economic but also involve complex ethical concerns. While digital marketing and data analytics provide convenience, they also raise significant ethical issues, particularly within the framework of behavioral economics.

Privacy Protection: In the digital environment, consumers' personal data has become a critical resource for marketing and decision-making. However, consumer data is often collected and used without sufficient consent, raising concerns about privacy violations. The "paradox of choice" in behavioral economics can also apply here, where consumers lack enough information to make fully informed decisions on digital platforms, making it difficult for them to effectively protect their privacy. Balancing data utilization with user privacy protection will be a key challenge for the digital economy moving forward.

Data Misuse: With the growth of big data and AI, companies may face the risk of misusing consumer data. For example, businesses might intentionally manipulate consumer purchasing decisions through opaque algorithms to increase profits. Behavioral economics' "choice architecture" theory can help us understand how companies design information and options to guide consumer decisions, but if such choices are not well-regulated, they can negatively impact consumers.

Algorithmic Bias: Algorithmic bias has emerged as a significant issue with the use of big data and machine learning. Since algorithms are trained on historical data, they may incorporate social, cultural, or gender biases, influencing decisions and recommendations. Consumers, unaware of these biases, may make irrational decisions influenced by algorithms on digital platforms. The study of “cognitive biases” in behavioral economics provides a valuable perspective in understanding this phenomenon.

Therefore, moving forward, businesses and governments need to address the ethical issues brought by digital technology more attentively, establishing stricter laws and regulations to ensure that the application of these technologies does not infringe on consumers’ basic rights.

6.2 Integration of Behavioral Economics and Digital Economy

With the continuous advancement of information technology, the integration of behavioral economics and the digital economy has become increasingly important, particularly in developing more refined consumer behavior models. Traditional behavioral economics theories are often based on laboratory research and hypothetical scenarios, but the digital economy provides a wealth of real-time data that can more accurately simulate consumer decision-making behaviors.

Precise Forecasting and Personalized Recommendations: In the digital economy, businesses can collect real-time consumer behavior data through big data and AI algorithms, while behavioral economics theory can help them better understand consumers’ irrational decisions in various contexts. Using these data, companies can achieve more accurate consumer behavior forecasting, leading to highly personalized marketing strategies. Concepts from behavioral economics, such as “bounded rationality” and “reference dependence,” can help understand how consumers make decisions in complex information environments, thus improving marketing effectiveness.

Digital Transformation of Behavioral Models: The digital economy not only provides new research data for behavioral economics but also compels the theory to evolve and update. For example, how to build more complex and dynamic consumer behavior models using multi-channel data (such as online browsing history and social media interactions) will be a key focus in future research. This behavioral economics based on real-time data and complex models will improve the precision and depth of consumer behavior analysis.

Cross-Disciplinary Integration and Innovation: The integration of behavioral economics with fields like information technology, data science, and psychology will open new avenues for consumer behavior research. By combining insights from these disciplines, scholars can develop more comprehensive consumer decision models to address real-world issues that traditional theories cannot solve. For example, the digital economy’s issues of “information overload” and “choice fatigue” can be better explained by behavioral economics through its integration with cognitive psychology and decision theory, offering deeper insights into consumer behavior in digital environments.

7. Conclusion

7.1 Policy Recommendations

7.1.1 Enhance Privacy Protection and Data Regulation

Governments should further improve data protection laws to ensure the security of consumer personal information in the digital environment. Enterprises should enhance transparency, clearly informing consumers about the purpose of data collection and usage, while respecting consumers’ right to choose and their privacy rights.

7.1.2 Regulate Algorithm Usage

Governments and industry organizations should implement regulations that ensure fairness and transparency in the use of algorithms for recommendation systems and personalized advertisements, to prevent algorithmic bias from negatively impacting consumer decision-making.

7.1.3 Promote Ethical Development of Digital Technologies

Industry standards and ethical frameworks should be developed with a focus on protecting consumers’ rights, especially addressing how digital technologies could be misused to guide consumers into making irrational decisions.

7.2 Practical Implications

7.2.1 Optimize Digital Marketing Strategies

Businesses should apply the principles of behavioral economics, such as anchoring effect, choice architecture, and reference dependence, to design pricing strategies and promotional activities that align with consumer psychology. For example, using limited-time offers, default options, and tiered pricing strategies can encourage consumers to make quick decisions.

7.2.2 Strengthen Personalized and Social Marketing

Businesses can use data analysis and social media platforms to offer personalized recommendations and social proof-based marketing campaigns, thereby increasing consumer engagement and loyalty. In doing so, it is important to ensure the transparency of marketing strategies and avoid infringing on consumer privacy.

7.2.3 Focus on Consumer Rights Protection

When designing digital payment systems and shopping platforms, businesses should reduce consumers' psychological burden through thoughtful design, such as providing clear payment information, avoiding complicated payment processes, and ensuring the security and privacy of consumers' funds and payments.

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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Research on the Role of Digital Economy in Promoting Rural Revitalization: A Study from the Perspective of Industrial Agglomeration

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Abstract: Rural revitalization is an essential pathway for socialist modernization and a crucial means of promoting common prosperity for all people. As a new form of productive force, the digital economy has become a key engine driving rural revitalization. This study adopts the theoretical framework of New Economic Geography and, from the perspective of industrial agglomeration, systematically explores the impact mechanism of the digital economy on rural revitalization at the theoretical level.

To further examine the impact of the digital economy on rural revitalization, this paper constructs a bidirectional panel fixed effects model, a mediation effect model, and a threshold regression estimation model for empirical testing. The research findings indicate that:

The digital economy has a significant positive impact on rural revitalization.

Industrial agglomeration plays a mediating role in the relationship between the digital economy and rural revitalization, where the digital economy promotes rural revitalization through industrial agglomeration. There exists a threshold effect of industrial agglomeration in the digital economy's promotion of rural revitalization. The continuous development of industrial agglomeration accelerates the positive effect of the digital economy on rural revitalization. Based on these findings, this paper proposes policy recommendations to foster rural digital talent, enhance the application of digital economy, and improve digital information platforms to promote rural industrial clustering, ultimately advancing comprehensive rural revitalization.

Keywords: Digital Economy; Industrial Agglomeration; Rural Revitalization

Published: May 26, 2025

DOI: <https://doi.org/10.62177/amit.v1i3.392>

1. Introduction

1.1 Research Background and Significance

1.1.1 Research Background

At present, China has achieved a comprehensive victory in poverty alleviation and successfully embarked on a new journey of socialist development. However, the “three rural” issues (agriculture, rural areas, and farmers) remain a top priority for the entire party. In 2017, at the 19th National Congress of the Communist Party of China, General Secretary Xi Jinping first proposed the rural revitalization strategy, elevating the priority development of agriculture and rural areas to the level of a national strategy. The 20th National Congress of the Communist Party of China emphasized the need to comprehensively

promote rural revitalization and build a modern socialist country in all respects. The No. 1 Central Document of 2023 further outlined the need to adhere to the priority development of agriculture and rural areas, promote urban-rural integration, and advance key tasks such as rural development, rural construction, and rural governance to fully implement rural revitalization. The No. 1 Central Document of 2024 once again stated that to advance Chinese-style modernization, it is essential to consolidate the foundation of agriculture and promote comprehensive rural revitalization as the overarching task of “three rural” work in the new era and new journey. Accelerating the modernization of agriculture and rural areas serves as a solid foundation for building a modern socialist country. Given this national strategic orientation, there is an urgent need for research on effectively addressing the “three rural” issues in the new era and promoting comprehensive rural revitalization.

Industrial prosperity is a crucial aspect of rural revitalization, and fostering advantageous industrial clusters can help shape a new pattern for this initiative. The “National Rural Industrial Development Plan (2020-2025)” highlights that developing rural industries is a fundamental pillar of comprehensive rural revitalization, an important support for consolidating and enhancing a well-off society, and a key driver for advancing agricultural and rural modernization. The process of industrial clustering leverages unique natural environmental resources to create distinctive competitive advantages (Bai Xiaozhong & He Yan, 2012), thereby enhancing industrial competitiveness (Zhou Haichuan et al., 2023) and providing momentum for comprehensive rural revitalization. Particularly with the rapid development and application of internet technology, the digital economy has become one of the major driving forces of China’s economic growth. The informatization of rural areas and the application of digital technology are increasingly integrated into industrial development, facilitating the aggregation of advantageous industries and becoming a critical factor influencing rural revitalization. The report of the 20th National Congress of the Communist Party of China proposed accelerating the development of the digital economy, promoting deep integration between the digital economy and the real economy, and creating globally competitive digital industry clusters. Digitalization can drive the healthy development of platform and shared economies, thereby upgrading industrial value chains and empowering the process of industrial clustering. Consequently, advancing industrial clustering to achieve comprehensive rural revitalization necessitates exploring the deep integration and application of the digital economy in rural industrial development—this serves as both the logical starting point of this research and a significant developmental opportunity.

1.1.2 Research Significance

At the theoretical level, this project is based on the theory of new economic geography and analyzes the intrinsic mechanisms through which the digital economy facilitates rural revitalization from the perspective of industrial clustering. This provides theoretical support for understanding the micro-level impact of the digital economy on rural revitalization.

At the practical level, this project promotes industrial clustering development through three key aspects: enhancing information exchange via the digital economy, driving industrial upgrading, and integrating the entire industrial chain. From this perspective, it provides theoretical support and practical guidance for government departments in formulating rural revitalization strategies and digital economy development plans.

1.2 Research Plan

1.2.1 Research Objectives

Constructing a Theoretical Analytical Framework for the Digital Economy’s Role in Rural Revitalization. Based on the theory of New Economic Geography, this study delves into the impact mechanism of the digital economy in promoting rural revitalization. From the perspective of industrial agglomeration, it clarifies the role of the digital economy in rural revitalization and establishes a theoretical logical framework for how the digital economy facilitates rural revitalization.

Developing an Empirical Model for the Digital Economy’s Role in Rural Revitalization. By integrating theoretical analysis with statistical data, this study employs a bidirectional fixed-effects panel regression model, a mediation effect model, and a threshold regression model to empirically examine the impact of the digital economy on rural revitalization through the scale effect of industrial agglomeration. This results in the formation of an empirical model for testing the role of the digital economy in rural revitalization.

Innovating Policy Support for the Digital Economy’s Role in Rural Revitalization. Based on the findings from research objectives (1) and (2), this study constructs a theoretical system for the digital economy’s role in rural revitalization. It

proposes innovative policy recommendations, including continuously cultivating digital talent in rural areas, fostering digital industry clusters, and improving digital information platforms. These measures aim to drive agricultural industrial agglomeration and comprehensively advance rural revitalization.

1.2.2 Technical Roadmap

This study integrates New Economic Geography theory to construct an index system for digital economy development and rural revitalization. Using industrial agglomeration as an intermediary variable, it collects panel data from 31 provinces in China from 2011 to 2022 and employs a bidirectional fixed-effects panel model and a mediation effect model to measure both the direct effect of the digital economy on rural revitalization and the indirect effect through industrial agglomeration. Furthermore, a threshold regression estimation model is constructed to determine whether there is a threshold effect between the digital economy and rural revitalization. Based on the empirical analysis results, targeted policy innovations for digital economy empowerment in rural revitalization are proposed.

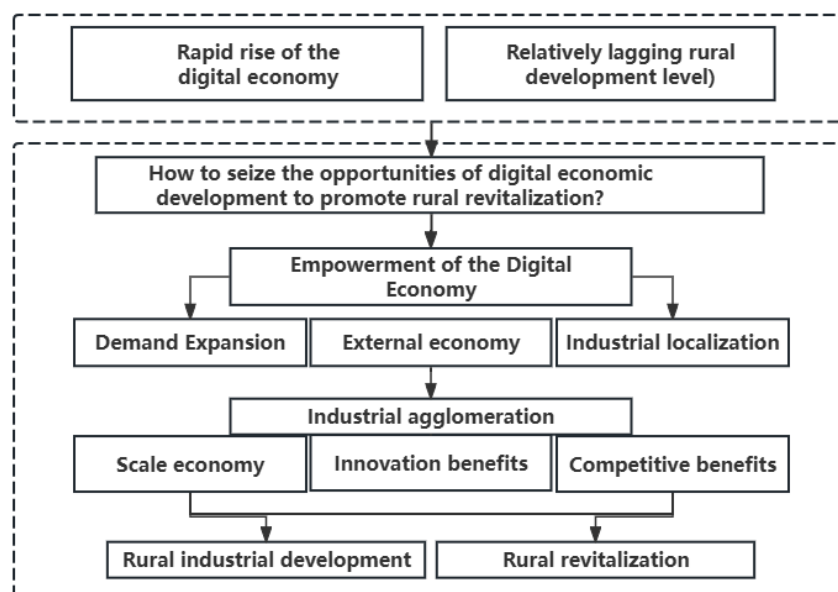
Compared with existing research, this study presents three key innovations:

First, based on previous studies, this research integrates New Economic Geography theory to systematically examine both the direct and indirect effects of the digital economy on rural revitalization from a theoretical perspective. New Economic Geography theory emphasizes the significance of spatial economic structures and industrial agglomeration. Within this theoretical framework, this study explores how the digital economy promotes industrial agglomeration and, in turn, empowers rural revitalization. By constructing an analytical framework that considers the geographical distribution of economic activities, it delves deeper into the interactions between the digital economy and industrial agglomeration and their impact on rural revitalization.

Second, this study examines the role of industrial agglomeration as a channel through which the digital economy facilitates rural revitalization, further exploring the synergistic mechanism between the digital economy and industrial agglomeration. This includes analyzing the application of digital technologies in industrial agglomeration and how industrial agglomeration fosters the development of the digital economy, thereby promoting rural revitalization. Research on this synergistic mechanism helps reveal the intrinsic relationship and mutual interactions between the digital economy and industrial agglomeration.

Third, this study provides new perspectives and methods for more precise rural revitalization policy formulation. By conducting an in-depth analysis of the coordinated development of the digital economy and industrial agglomeration, policymakers can more accurately identify the key bottlenecks and opportunities in rural revitalization. This enables the development of more effective policies and measures to enhance rural revitalization through targeted digital economy applications.

Figure 1 Technical Roadmap



2.Literature Review

2.1 Domestic and International Research Status

As China enters a new stage of socialist development, the “three rural” (agriculture, rural areas, and farmers) issues remain a top priority for the entire Party. The 2023 Central No. 1 Document, titled “Opinions of the CPC Central Committee and the State Council on Learning from the ‘Thousand Villages Demonstration, Ten Thousand Villages Renovation’ Project to Effectively Promote Comprehensive Rural Revitalization”, is the 12th No. 1 document issued since the 18th National Congress of the Communist Party of China, highlighting the continuous central focus on rural development. The document emphasizes that advancing Chinese-style modernization requires a steadfast commitment to strengthening the agricultural foundation and comprehensively promoting rural revitalization. Accelerating agricultural and rural modernization is the solid foundation for building a modern socialist country in all aspects.

As the dominant economic form following agricultural and industrial economies, the digital economy has become a key driver in reorganizing rural resource elements and reshaping rural economic structures. At this critical period of digital economy development, the question of how to leverage the digital economy to drive rural revitalization remains a crucial issue for rural development.

2.1.1 Driving Mechanism of the Digital Economy in Promoting Rural Revitalization

With the continuous improvement and development of information technology, advancements in digital technology are driving the growth of rural areas. At present, the digital economy is increasingly integrated with rural industrial development, becoming a new engine and driving force for the rural revitalization strategy. This study primarily explores the driving mechanism of the digital economy in rural revitalization by analyzing how it fosters the development of new rural industries and business models, promotes industrial agglomeration, and ultimately drives comprehensive rural revitalization.

Leveraging its distinctive characteristics, the digital economy facilitates industrial agglomeration through three key aspects: enhancing information exchange, driving industrial upgrading, and integrating the entire industrial chain. From the perspective of information exchange, the digital economy’s strong information-sharing capabilities help reduce information asymmetry in industrial development (Huang Yongchun et al., 2022). By utilizing intelligent platforms to collect and process information, the digital economy enhances search efficiency, reduces initial costs of industrial development, and improves the supply-demand matching of supply chains, value chains, and innovation chains (Wang Wei & Wei Kehui, 2024)^[1], ultimately optimizing resource allocation efficiency (Bai Peiwen & Yu Li, 2021). Additionally, under the digital economy model, digital inclusive finance can effectively lower transaction costs and improve transaction efficiency, thereby strengthening industrial agglomeration (Li Xiaoyuan & Liu Yumeng, 2021).

From the perspective of industrial upgrading, the digital economy, as a core element of industrial transformation, fundamentally restructures various aspects of economic activities (Hou Jian & Liu Qing, 2022)^[2]. By promoting digitalization, greening, and low-carbon transformation of rural agriculture, the digital economy generates a synergistic effect greater than the sum of individual contributions (Han Jian & Li Jiangyu, 2022), enabling the upgrading of traditional agriculture (He Leihua et al., 2022, pp.1-18) and providing new momentum for industrial agglomeration (Zhang Yongheng & Chen Mei, 2022)^[3].

From the perspective of integrating the entire industrial chain, the digital economy enhances agricultural production through digital technology empowerment (Tian Ye et al., 2021), promotes the digital, networked, and intelligent transformation of rural industries, and enables horizontal and vertical industry linkages with positive feedback effects, spreading to other closely related sectors (Guo Chaoxian & Miao Yufei, 2023). This fosters the deep integration of the primary, secondary, and tertiary agricultural industries, driving efficient collaboration in rural characteristic industries (Jiang Xiaojun & Jin Jing, 2022)^[4], and promoting the construction and development of industrial agglomeration (Wu Jingwei & Jiang Jing, 2021).

Industrial agglomeration stimulates related industries, attracting new investments and offering fresh development momentum for rural areas. It enhances farmers’ income, fosters specialized rural industries, and accelerates technology diffusion, thereby promoting rural revitalization.

First, industrial agglomeration provides new income channels for farmers. As industry scales expand, improvements in

mechanization, technological efficiency, labor specialization, and market bargaining power due to agglomeration economies significantly enhance regional agricultural productivity and efficiency (Zhang Zhexi et al., 2018)^[5], thereby increasing farmers' incomes. Additionally, industrial agglomeration helps enhance labor productivity and production efficiency (Li Jing, 2023), freeing up rural labor for other economic activities, diversifying income sources, and further supporting rural revitalization.

Second, industrial agglomeration fosters the development of specialized rural industries. Industrial agglomeration capitalizes on location advantages, bringing together a large number of related enterprises in a given area, thereby forming a sustained competitive advantage (Yang Xiuyun et al., 2021). Rural leading industries with unique characteristics and comparative advantages tend to cluster geographically, benefiting from agglomeration effects (Sun Hui, 2007). By deepening and expanding specialized rural industries and products, rural areas can strengthen their distinctive economic advantages (Guang Ya, 2018) and convert comparative resource advantages into competitive economic advantages (Yang Yadong et al., 2023)^[6], thereby effectively advancing comprehensive rural revitalization.

Third, industrial agglomeration accelerates technology diffusion. In the process of industrial agglomeration, businesses must enhance their knowledge accumulation, knowledge flow, and knowledge absorption to improve both their internal capabilities and external contractual relationships (Meng Ziheng et al., 2022)^[7], facilitating specialized technology learning. Additionally, increased economic interaction within industrial clusters accelerates information and technology dissemination (Liu Xuehua et al., 2018), leading to technology spillover effects (Zhang Aili & Zhang Xinyu, 2023), ultimately stimulating rural economic growth and promoting comprehensive rural revitalization.

2.1.2 Implementation Pathways of the Digital Economy in Promoting Rural Revitalization

In the new era, rural development has achieved some success under the impetus of the digital economy. However, there are still challenges such as weak digital technology infrastructure, low levels of digitalization and application, and a shortage of specialized talents in rural areas. Based on the driving mechanisms of the digital economy in promoting rural revitalization, this study explores the implementation pathways from the perspectives of integrating the digital economy into rural multi-stakeholders, establishing digital technology research and application platforms, and cultivating specialized digital technology talents to facilitate the process of digital economy-driven rural revitalization.

Integrating the digital economy into rural industrial development is the direct pathway through which the digital economy promotes rural revitalization. The digital economy can only serve as a new engine for industrial agglomeration when deeply integrated with rural enterprises. Local governments should accelerate the promotion of key digital agricultural technologies in agricultural production and enhance innovation and technical exchanges among enterprises (Song Changying et al., 2022), thereby reducing transaction and financing costs for businesses (Fang Fuqian et al., 2023). Meanwhile, the digitalization of knowledge, information, and human resources should be facilitated to enhance infrastructure digitalization, allowing digital technology to be better incorporated into rural enterprise production (Zhao Deqi & Ding Yiwen, 2021). This approach can inject new momentum into the transformation and upgrading of traditional industries (Liu Yang et al., 2020)^[8].

Establishing digital technology research and application platforms is the fundamental pathway for the digital economy to promote rural revitalization. The application of digital technology depends on technological development from universities and agricultural research institutions, as well as promotion and implementation by government platforms. It is necessary to actively encourage collaboration between universities, research institutes, and agricultural enterprises to improve the efficiency of technology commercialization in agriculture and address challenges in digital agriculture development (Feng Chaorui & Xu Hongyu, 2021). Additionally, the government should leverage leading large-scale agricultural enterprises to guide the digitalization of industries, using rural digital leaders to drive industrial integration (Song Xuguang et al., 2022). For small and medium-sized enterprises (SMEs), targeted policies should be introduced to promote the agglomeration and development of rural SMEs (Liu Shuchun et al., 2021). Furthermore, enhancing digital awareness and skills among rural workers is crucial (Wang Ruifeng, 2022), which requires organizing specialized training programs on the digital economy (Ma Huanglong & Qu Xiao'e, 2022)^[9].

Cultivating specialized digital technology talents is the effective pathway for the digital economy to drive rural revitalization.

Human capital serves as the internal driving force for the digital economy's role in rural revitalization (He Leihua et al., 2022, pp.1-18). The rapid advancement of the digital economy places higher demands on the workforce (Liu Xiaoming, 2023)^[10]. To ensure sustainable rural development, it is essential to continuously expand the pool of digital talents in rural areas, thereby enhancing the vitality of rural industrial development (Zhang Yunping & Luan Jing, 2022). The government should establish and improve a digital training system for rural residents, selecting a group of digitally capable and willing rural residents to participate in vocational digital skills training, providing high-quality labor for industrial agglomeration (Wang Haixia et al., 2023)^[11]. Additionally, it is crucial to cultivate a new generation of farmers who are proficient in networking, passionate about agriculture, and skilled in business operations, thereby fostering new rural business entities and stimulating the intrinsic driving force of rural industrial development (Zhang Wang & Bai Yongxiu, 2022).

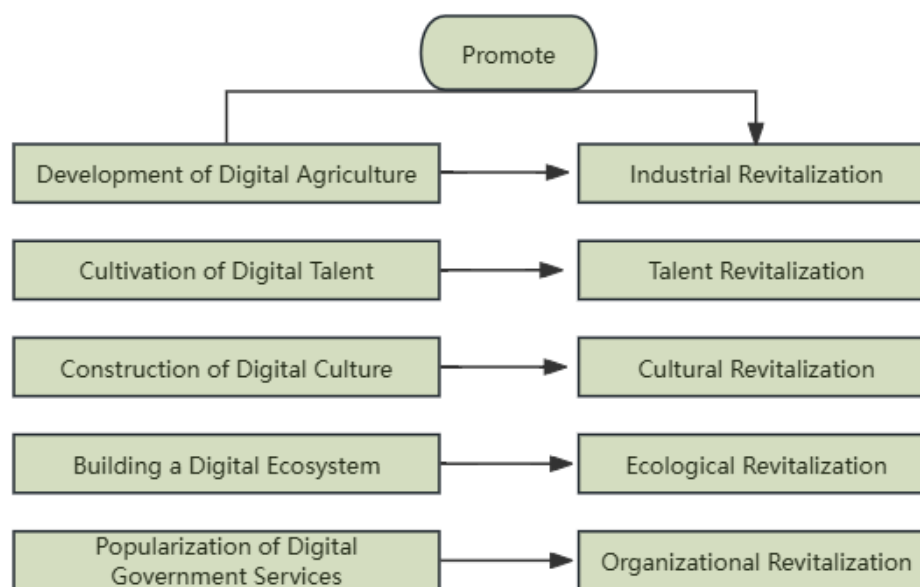
3.Theoretical Mechanism of the Digital Economy in Promoting Rural Revitalization

3.1 Direct Impact of the Digital Economy on Rural Revitalization

This study, based on the “Five Revitalizations” strategy of rural revitalization, explores the direct impact of the digital economy in empowering industrial, talent, cultural, ecological, and organizational revitalization^[12]. The focus is on how the digital economy facilitates rural industrial revitalization.

The digital economy promotes rural industrial revitalization by advancing digital agriculture. With the continuous integration of big data, cloud computing, and other digital technologies into agriculture, the modernization and smart development of agriculture have significantly improved, effectively enhancing agricultural production efficiency. Supported by digital technology, the emergence of digital e-commerce and digital logistics platforms has extended agricultural industry chains and increased the added value of agricultural products. Under the empowerment of digital technologies, new agricultural management systems are rapidly forming, accelerating the transformation of rural business entities toward family farms, farmer cooperatives, and leading enterprises, thereby improving agricultural industry operational efficiency. The development of rural industries directly creates diverse and extensive employment opportunities for local farmers, effectively narrowing the urban-rural income gap and advancing the realization of rural revitalization.

Figure 2 Pathways Through Which the Digital Economy Directly Influences Rural Revitalization



The digital economy drives rural talent revitalization through digital talent cultivation. The digital transformation of agriculture and rural areas cannot be achieved without the support of digital talent. Against the backdrop of the integration of the digital economy and the real economy, efforts to cultivate digital economy talent have been significantly enhanced. The mechanism for attracting rural digital talent has continuously improved, promoting the enhancement of farmers' digital skills and literacy. This enables farmers to effectively use modern agricultural production technologies and information infrastructure, thereby boosting the overall efficiency and modernization of rural production activities.

The digital economy facilitates rural cultural revitalization by promoting digital cultural development. As the digital economy

integrates with rural culture, digital technologies are increasingly applied to rural landscapes, folk activities, and other cultural settings. This not only stimulates rural tourism development but also creates new opportunities for rural cultural dissemination. By leveraging new media and digital platforms, the digital economy enhances villagers' participation in cultural activities, improves the overall ideological and cultural level of farmers, and advances the construction of rural spiritual civilization.

The digital economy promotes rural ecological revitalization by fostering a digital ecological environment. Within the broader context of digital technology empowering rural revitalization, the application of digital water management, soil improvement technologies, and other innovations has significantly enhanced water quality and soil conditions in rural areas, contributing to the restoration of rural ecosystems. The establishment of digital air quality forecasting systems and automated water quality monitoring systems provides efficient support for environmental management, enabling dynamic monitoring and scientific early warning of rural ecological conditions. These systems facilitate regional ecological data sharing, thereby enhancing rural ecological governance and development.

The digital economy drives rural organizational revitalization through the promotion of digital governance. The development of digital governance has transcended traditional rural governance models. By utilizing big data, artificial intelligence, and other digital technologies, digital governance platforms can accurately assess the real needs of rural residents, optimize public service systems, and improve the overall welfare of rural communities. The widespread adoption and application of the internet and modern communication technologies eliminate physical space constraints, empowering rural grassroots self-governance. By integrating online and offline decision-making models, villagers can actively participate in rural governance, thereby enhancing the vitality of community self-governance.

The digital economy has had a positive impact on all five aspects of rural revitalization—industrial revitalization, talent revitalization, cultural revitalization, ecological revitalization, and organizational revitalization. Based on this, the study proposes the following hypothesis:

H1: The digital economy has a direct and positive impact on rural revitalization.

3.2 Impact of Digital Economy-Enabled Rural Industrial Agglomeration on Rural Revitalization

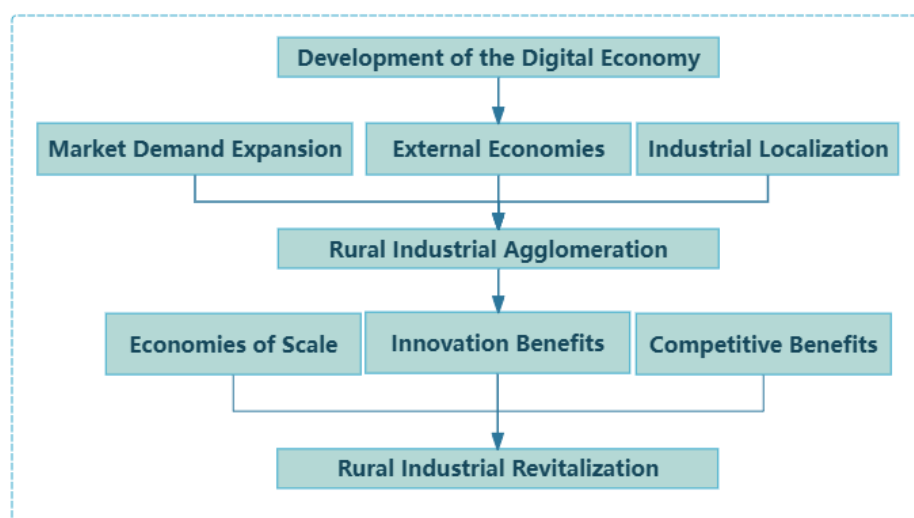
This study analyzes the theoretical mechanism of how the digital economy enables rural industrial agglomeration to drive rural revitalization, which is divided into two parts. First, based on New Economic Geography theory, this study explores the theoretical mechanism of the digital economy in facilitating rural industrial agglomeration. Second, by combining the agglomeration effects of industrial clusters with rural industrial development, this study examines how rural industrial agglomeration promotes rural industrial revitalization, ultimately leading to comprehensive rural revitalization.

New Economic Geography theory states that demand factors, external economies, and industrial localization are the three key conditions for forming industrial agglomeration. The digital economy, characterized by inclusiveness, innovation, and strong penetration, plays an active role in these three conditions, thereby promoting rural industrial agglomeration. First, in terms of demand factors, in regions with strong demand, transaction costs between suppliers and buyers are relatively low, and convenient transportation conditions make it easier to generate increasing returns to scale. The popularization of rural internet has broken the urban-rural information barrier, reducing transaction costs between supply and demand and expanding the market for rural products. The application of Internet of Things (IoT) technology has optimized urban-rural logistics efficiency, lowered logistics costs, and enhanced the market competitiveness of rural products, thereby increasing product demand. Second, New Economic Geography theory categorizes external economies into labor market pooling, specialized intermediate products and services, and technological spillovers. The digital economy promotes these aspects in multiple ways. The emergence of digitalized multi-employment and labor security service platforms has mitigated structural and frictional mismatches in the labor market, allowing rural industries to attract and accumulate more technical talent, thereby playing the “reservoir effect” in the labor market. The development of digital logistics, inclusive finance, and digital cultural industries provides specialized intermediate products and services, enhancing the innovation capacity and industrial competitiveness of rural industries. The network externality and spillover effects of digital technology and its applications further contribute to the formation of rural industrial clusters. Finally, as the national rural industry development plans, such

as “One Village, One Product”, “One Town, One Specialty”, and “One County, One Industry”, are continuously implemented, the localization trend of rural industries is strengthening. The establishment of digital and modern agricultural industrial parks has created favorable conditions for rural industrial agglomeration.

The digital economy, as a new economic paradigm, has played a positive role in fostering rural industrial agglomeration, further driving the development and revitalization of rural industries.

Figure 3 Pathways Through Which the Digital Economy Achieves Rural Industrial Revitalization via Rural Industrial Agglomeration



Rural industrial agglomeration fosters an integrated and synergistic rural industrial development model by leveraging external economies of scale, innovation benefits, and competitive advantages, thereby promoting rural revitalization through industrial revitalization.

First, the continuous concentration of rural enterprises leads to external economies of scale, facilitating internal division of labor and cooperation within rural industries. External economies of scale reduce raw material search and transaction costs for upstream and downstream enterprises in production, refine industrial chain specialization, enhance labor productivity, and enable more efficient use of rural infrastructure, providing necessary supporting products and services for production. In terms of product sales, industrial clusters improve bargaining power, attract increased government investment in public services and infrastructure, and enhance rural industrial productivity.

Second, rural industrial agglomeration drives innovation by increasing personnel mobility and communication among rural enterprises, fostering innovative thinking among employees, and accelerating the generation of new ideas. Moreover, the clustering of rural enterprises facilitates knowledge and technology spillovers, expediting the dissemination of new agricultural production technologies and processes, thereby enhancing rural industrial technological innovation and application capabilities.

Finally, rural industrial agglomeration intensifies competition, compelling rural enterprises to continuously reduce costs, adopt advanced agricultural production technologies, improve product quality, and enhance both production efficiency and competitiveness. By stimulating rural industrial growth, industrial agglomeration plays a crucial role in driving rural revitalization.

However, the digital divide may exist in regions with varying levels of digital economic development. In digitally advanced areas, rural industries benefit from widespread adoption of digital technology, higher levels of farmer digital literacy, and greater contributions of industrial agglomeration to rural revitalization. In contrast, digitally underdeveloped regions face a more pronounced digital divide, preventing some farmers from participating in the digital economy and hindering the adoption of digital technologies in rural industries, thereby limiting the impact of industrial agglomeration on rural revitalization.

Based on this, the following hypotheses are proposed:

H2: The digital economy influences rural revitalization by affecting industrial agglomeration.

H3: Industrial agglomeration has a nonlinear impact on rural revitalization.

4. Empirical Test of the Digital Economy in Promoting Rural Revitalization

4.1 Model Construction

4.1.1 Bidirectional Fixed-Effects Panel Model

To examine the impact of the digital economy on rural revitalization, a bidirectional fixed-effects model is established to verify the direct impact relationship. The model is specified as follows:

$$Re_rural_{it} = \alpha_0 + \alpha_1 Dig_{it} + X_{it} + \varepsilon_{it} \quad (1)$$

represents the rural revitalization score of province *iii* in year *t*, denotes the level of digital economy development of province *iii* in year *t*, represents a series of control variables affecting rural revitalization, is the random error term.

4.1.2 Mediation Effect Model

Based on the verification of the coefficient α_1 in equation (1), which measures the impact of the digital economy on rural revitalization, and following the theoretical analytical framework, a three-stage mediation effect model is constructed to examine the mediating role of industrial agglomeration in the relationship between the digital economy and rural revitalization. The model is specified as follows:

$$Industrial_{it} = \beta_0 + \beta_1 Dig_{it} + \beta_{it} X_{it} + \varepsilon_{it} \quad (2)$$

$$Re_rural_{it} = \gamma_0 + \gamma_1 Dig_{it} + \gamma_2 Industrial_{it} + \gamma_{it} X_{it} + \varepsilon_{it} \quad (3)$$

4.1.3 Panel Threshold Model

To empirically examine the threshold effect of industrial structure in the relationship between the digital economy and rural revitalization, the panel threshold model is constructed as follows:

$$Re_rural_{it} = \lambda_0 + \lambda_1 Dig_{it} + I(Industrial_{it} \leq \theta) + \lambda_2 Dig_{it} + I(Industrial_{it} > \theta) + \lambda_{it} X_{it} + \varepsilon_{it} \quad (4)$$

In equation (4), represents the threshold value, and is an indicator function that takes the value 1 when the condition inside is met and 0 otherwise.

4.2 Variable Selection

4.2.1 Dependent Variable: Rural Revitalization Index (Re_rural)

The dependent variable is rural revitalization. There is no universally accepted measurement standard in academic research. Based on the requirements of the 19th National Congress of the Communist Party of China on rural revitalization, this study draws on existing research indicators (Zhang Ting et al., 2018)^[13] and constructs a rural revitalization index system from five dimensions: industrial prosperity, ecological livability, cultural flourishing, effective governance, and affluent living standards. The specific indicators are shown in Table 1. To avoid multicollinearity issues, this variable is log-transformed and denoted as $\ln Y$.

Table 1 Comprehensive Index of Rural Revitalization

Primary Indicator	Secondary Indicator	Attribute	Weight
Industrial Prosperity	Per Capita Primary Industry Output Value	+	0.065007
	Grain Production	+	0.2097
	ln Total Agricultural Machinery Power	+	0.047427
	ln Effective Irrigation Area	+	0.063023
Ecological Livability	Forest Coverage Rate	+	0.112117
	Household Garbage Harmless Disposal Rate	+	0.018068
	ln Number of Public Toilets	+	0.014573
	Number of Rural Doctors and Health Workers	+	0.133027
	ln Comprehensive Water Supply Production Capacity	+	0.030978
Cultural Flourishing	ln Local Government Education Expenditure	+	0.009785
	Literate Population / Number of People Aged 15 and Above	-	0.013345
	TV Program Coverage Rate	+	0.017411

Primary Indicator	Secondary Indicator	Attribute	Weight
Effective Governance	Per Capita Disposable Income of Rural Residents / Per Capita Disposable Income of Urban Residents	+	0.058891
	Per Capita Consumption Expenditure of Rural Residents / Per Capita Consumption Expenditure of Urban Residents	+	0.038297
	In Rural Population	+	0.089632
Affluent Living Standards	In Per Capita Disposable Income of Rural Residents	+	0.045286
	In Per Capita Food, Tobacco, and Alcohol Consumption Expenditure of Rural Residents	+	0.031298
	In Number of Rural Employment	+	0.05128

4.2.2 Core Independent Variable

Digital Economy Development Level (Dig). There is no universally accepted framework in academia for constructing digital economy indicators. This study draws on existing research (Yang Chengjia & Li Zhongxiang, 2023)^[14] and establishes a digital economy development index system based on four dimensions: digital infrastructure, digital industrialization, industrial digitalization, and digital inclusive finance. The entropy method is used to measure the digital economy development level across different provinces in China, with the specific indicators detailed in Table 2. To mitigate multicollinearity issues, the variable is log-transformed and denoted as $\ln X$.

Table 2 Comprehensive Index of Digital Economy

Primary Indicator	Secondary Indicator	Attribute	Weight
Digital Infrastructure	Internet Penetration Rate	+	0.06636
	Mobile Phone Penetration Rate	+	0.043356
	Optical Cable Line Length		0.102002333
Digital Industrialization	Total Telecom Business Volume	+	0.085871
	Number of Urban Employees in Information Transmission, Software, and IT Services	+	0.111873
	Software Business Revenue	+	0.121085
	Scale of Information Technology Service Revenue	+	0.10673
Industrial Digitalization	Proportion of Employees in Computer Services and Software Industry	+	0.057957
	Rural Electricity Consumption	+	0.143237
	E-commerce Sales Revenue	+	0.107292914
Digital Inclusive Finance	Digital Inclusive Finance Index	+	0.054235

4.2.3 Mediating Variable / Threshold Variable: Industrial Agglomeration Index (Ind-a)

Industrial agglomeration refers to the process of industries concentrating in specific regions, reflecting the spatial concentration characteristics of production resources. Based on the research context of this study, location entropy is used to measure industrial agglomeration. It is calculated as the ratio of the share of employment in the primary industry of a specific region to the national total primary industry employment, divided by the share of total employment in that region to the national total employment.

4.2.4 Control Variables

Considering the impact of fiscal expenditure, economic level, and fixed investment on rural revitalization, this study includes the following control variables:

Fiscal Support for Agriculture (Fis): Measured by the proportion of government expenditure on agriculture, forestry, and water affairs to total fiscal expenditure.

Economic Development Level (Dev): Measured by the natural logarithm of per capita GDP in each province.

Fixed Asset Investment (Fai): Measured by the fixed asset investment amount in each province.

4.3 Data Sources

Table 3 Descriptive Statistics of Variables

Variable	Variable Description	Sample Size	Mean	Standard Deviation	Min Value	Max Value
lnY	Log of Rural Revitalization Development Level	372	-0.897	0.287	-1.567	-0.570
lnX	Log of Digital Economy Development Level	372	-1.993	0.640	-3.201	-0.884
Fis	Fiscal Support for Agriculture	372	0.115	0.034	0.004	0.204
Dev	Economic Development Level	372	10.856	0.462	9.682	12.156
Fai	Fixed Asset Investment	372	19193.25	14846.34	516.31	65087.93
Ind-a	Industrial Agglomeration Index	372	0.259	0.507	4.42e-10	3.063

This study selects panel data from 31 provinces in China from 2011 to 2022 for empirical analysis. The data are sourced from the China Statistical Yearbook, provincial and municipal statistical yearbooks, and local statistical bureaus. Additionally, to ensure data completeness, scientific accuracy, and practical applicability, interpolation methods were used to fill in a small number of missing values. The descriptive statistics of each variable are shown in Table 3.

4.4 Empirical Results Analysis

4.4.1 Baseline Regression Results Analysis

According to the Hausman test, this study adopts a fixed-effects model for empirical analysis, and the results are shown in Table 4. From the table, it can be observed that the digital economy has a positive promoting effect on rural revitalization. Therefore, Hypothesis H1 is confirmed.

Table 4 Baseline Regression Results

	(1)	(2)	(3)	(4)
LNK	0.110*** (8.76)	0.105*** (8.13)	0.0911*** (6.67)	0.0816*** (6.50)
Fis		0.225*** (2.67)	0.289*** (3.79)	-0.102*** (-2.64)
Dev			0.103** (2.92)	0.192*** (5.62)
Fai				-0.00000283*** (-8.05)
Constant	-1.027*** (-38.71)	-1.050*** (-33.38)	-2.251*** (-5.46)	-3.252*** (-8.20)
R ²	0.99	0.99	0.99	0.99

* p<0.05, ** p<0.01, *** p<0.001

4.4.2 Mediation Effect Model

To verify the existence of an indirect effect mechanism between the digital economy and rural revitalization, this study selects industrial agglomeration level as a mediating variable for empirical analysis. The regression results are shown in Table 5.

As indicated in Table 5, the total effect of the digital economy on rural revitalization is 0.418, while the direct effect is 0.0932. Since the direct effect is smaller than the total effect, the mediation effect is present.

Thus, industrial agglomeration plays a mediating role in the process of the digital economy promoting rural revitalization, confirming Hypothesis H2.

Table 5 Mediation Effect Regression Results

	(1)	(2)
industrial		0.0277** (3.19)
lnx	0.418*** (5.30)	0.0932*** (7.23)
Fis	2.870** (2.86)	-0.181 (-1.14)
fai	0.0000103*** (4.67)	-0.00000311*** (-8.70)
dev	-0.275*** (-3.78)	0.199*** (5.91)
Constant	2.23*** (2.89)	-3.314*** (-8.46)
R ²	0.87	0.99
Total Effect	0.418	
Direct Effect	0.0932	
Indirect Effect	0.3248	

* p<0.05, ** p<0.01, *** p<0.001

4.4.3 Threshold Effect Test and Threshold Value Determination

Before conducting the threshold regression test, it is necessary to verify whether a threshold effect exists. If a threshold effect is detected, the number of thresholds and their values are further calculated. The test results are shown in Table 6. Based on the results, a single-threshold regression model is selected.

Table 6 Threshold Test Results

Threshold Type	F Statistic	10% Critical Value	5% Critical Value	1% Critical Value
Single	38.47*	25.5602	31.03	44.60
Double	16.24	21.6613	25.76	36.03

* p<0.05, ** p<0.01, *** p<0.001

The regression results of the threshold model are shown in Table 7. It can be observed that the threshold value is 0.1071. When the threshold value is not exceeded, the coefficient is 0.0998 and statistically significant. However, after surpassing the single threshold value, the coefficient increases, indicating that the positive impact of the digital economy on rural revitalization becomes more significant. This result suggests that the effect of the digital economy on rural revitalization through industrial structure is not continuous, thereby confirming Hypothesis H3.

Table 7 Threshold Effect Regression Estimation Results

Lny(Inda≤0.1071)	0.0998
Lny(Inda>0.1071)	0.1182
Control Variables	Control Variables
Constant	-3.171***(-5.76)

4.5 Empirical Conclusions

This study utilizes panel data from 31 provinces in China from 2011 to 2022. Based on the construction of rural revitalization and digital economy indicator systems, the entropy method is employed for measurement. Additionally, the bidirectional fixed-effects baseline regression model, mediation effect model, and threshold regression model are used to analyze the impact of the digital economy on promoting rural revitalization.

The empirical results show that: first, the digital economy has a significant positive impact on rural revitalization; second,

industrial agglomeration plays a mediating role in the relationship between the digital economy and rural revitalization, demonstrating that the digital economy can promote rural revitalization through industrial agglomeration; third, there is a threshold effect in the process of the digital economy promoting rural revitalization through industrial agglomeration. The continued development of industrial agglomeration can further accelerate the role of the digital economy in promoting rural revitalization.

5. Policy Recommendations

To fully leverage the digital economy in promoting rural revitalization and address the bottlenecks in rural industrial development, government policies should be further improved to support comprehensive rural revitalization. Based on the pathway in which the digital economy fosters industrial agglomeration and thereby drives rural revitalization, efforts should focus on facilitating rural industrial agglomeration to achieve comprehensive rural revitalization. Therefore, to develop the rural digital economy and enhance industrial agglomeration, policies should be strengthened in the following areas: continuous cultivation of rural digital talent, promotion of digital technology applications, and improvement of rural digital information platforms.

The first priority is to cultivate digital economy talent, which is an essential guarantee for achieving rural industrial agglomeration. Given the current shortage of digital economy professionals, the government should strengthen efforts to train rural digital talent and enhance farmers' digital literacy and skills. First, top-level planning, policy intervention, and coordinated collaboration should be enhanced, with targeted digital infrastructure development and intervention policies formulated to address existing rural development challenges. Second, the coverage of digital technology in rural areas should be expanded, utilizing administrative measures to facilitate the transmission of resources, expanding access to 5G, big data, and artificial intelligence, and lowering the barriers for farmers to engage with digital technology. Third, network-based training programs should be emphasized, providing farmers with practical opportunities in e-commerce live streaming, teaching them how to utilize new media tools, capture market information, and conduct digital marketing through mobile applications. Fourth, training content should be designed scientifically, helping farmers master smart agriculture software and digital tools, thereby improving their ability to apply digital solutions in agricultural production.

The second priority is to promote the agglomeration of rural specialty industries, which requires digital technology to drive the transformation and upgrading of agricultural industries. First, digital technology should be deeply integrated with traditional agriculture, enhancing the modularization of the agricultural industry system to form an interconnected, efficient, and secure industrial chain, achieving low-cost, high-quality, and fast logistics, and fostering new agricultural industries, business models, and markets. Second, modern technologies such as the internet, big data, and cloud computing should be leveraged for digital empowerment, upgrading agricultural production facilities to enhance intelligent, information-based, and modernized agricultural production, establishing an integrated information platform for production and sales, and promoting the development of "Internet + Agriculture." Third, technological upgrades should be prioritized in modern agricultural development, embedding digital technology into traditional production factors such as land, capital, and labor, expanding agricultural production scales appropriately to address market risks, while also utilizing digital technology to reshape traditional agricultural business models, thereby controlling uncertainties caused by large-scale production and ensuring the smooth transformation and upgrading of agricultural production.

The third priority is to maximize the increasing marginal benefits and external economies of the digital economy by improving rural digital information platforms to facilitate data circulation and sharing. First, technological and business model innovation should be encouraged. The government should provide funding support for research and development, promoting the adoption of new technologies such as artificial intelligence, the Internet of Things, and big data in rural digital information platforms to enhance their intelligence and automation, improving service efficiency. Additionally, rural digital platforms should be encouraged to explore new operational and service models, such as direct sales of agricultural products via social networks and digital promotion of rural tourism, to meet the evolving needs of rural development. Second, existing e-commerce platforms should be utilized to expand rural product sales channels. The government should facilitate close collaboration between e-commerce platforms and agricultural producers, promoting the upward mobility of agricultural

products in digital markets to increase farmers' incomes. Additionally, e-commerce regulations should be improved to combat online fraud, counterfeit products, and other violations, ensuring a sound legal environment for the healthy development of rural e-commerce platforms. Third, the functionality of rural e-government services should be enhanced, and data sharing should be strengthened. E-government service platforms should provide one-stop digital services, including online consultations, applications, and inquiries, making it easier for rural residents and enterprises to access public services. Furthermore, interdepartmental data sharing should be promoted to eliminate information silos and improve the efficiency and quality of e-government services.

By focusing on cultivating rural digital talent, promoting digital technology applications, and improving rural digital information platforms, policy measures can effectively empower the development of rural industrial clusters, thereby utilizing industrial agglomeration to drive comprehensive rural revitalization.

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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Problems of Lagging Brand Building of Agricultural Products Affecting Market Competitiveness and Countermeasures of Traceability System

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Abstract: The current construction of agricultural product brands faces core problems such as product homogenization, insufficient quality and safety assurance, limited brand communication channels, and weak premium ability. The root cause lies in the interweaving of multiple factors such as limited capacity of agricultural production entities, lagging government support services, and dynamic changes in market consumption demand. As a key path to solving the above difficulties, the traceability system builds the core support for agricultural product brand construction through the synergistic effects of quality and safety assurance, consumer trust enhancement, brand differentiation development, and agricultural industry upgrading. However, the current traceability system still faces bottlenecks such as fragmented policy supply, inconsistent technical standards, and low participation of stakeholders. It is urgent to achieve breakthroughs through systematic measures such as strengthening policy guidance, improving technical specifications, and stimulating the driving force of stakeholders, ultimately promoting the construction of agricultural product brands towards a new stage of high-quality development.

Keywords: brand building of agricultural products; Traceability system; Quality and safety; Consumer Trust

Published: Jun 5, 2025

DOI: <https://doi.org/10.62177/amit.v1i3.428>

introduction

In the process of agricultural modernization, the construction of agricultural product brands has become a core proposition for enhancing industrial competitiveness(Lu et al., 2024). As a trust bridge connecting production and consumption, the traceability system provides an innovative path to solve the dilemma of agricultural product brand building through mechanisms such as data transparency and quality traceability. This article constructs a systematic analysis framework for the construction of agricultural product brands from problem diagnosis, root cause analysis, value reconstruction, to countermeasure design, aiming to provide theoretical support and practical guidance for the high-quality development of agriculture.

1.The specific problem of lagging behind in the construction of agricultural product brands affecting market competitiveness

1.1 Serious homogenization of products

The phenomenon of homogenization in the agricultural product market covers the entire industry. Many agricultural products exhibit high similarities in variety, appearance, taste, and other aspects, lacking unique product features and differentiated competitive advantages. Taking the fruit market as an example, apples are a common fruit for mass consumption. Apples

from different regions mostly present a round and full shape, with a reddish color that is tempting, and a taste that is mainly sweet and refreshing. Consumers often find it difficult to accurately distinguish the specific origin and brand of apples based solely on their appearance and taste, and can only make simple choices based on price. This homogenization phenomenon makes agricultural products easily trapped in price wars in the market, resulting in low added value of products and significant compression of profit margins(Li, 2024). The reasons for the serious homogenization of agricultural products are multifaceted. Agricultural producers have long been influenced by traditional planting concepts and are accustomed to following the trend of popular agricultural product varieties in the market, lacking keen insight and innovative awareness of changes in market demand. The investment in agricultural technology research and development is relatively insufficient, and the promotion and application of new varieties and technologies are slow, making it difficult to meet the market's demand for diversified agricultural products. The low degree of standardized production of agricultural products and the lack of unified quality standards and production norms have further exacerbated the problem of product homogenization.

1.2 Quality and safety are difficult to guarantee

The quality and safety of agricultural products are the cornerstone of brand building, but the current issues of agricultural product quality and safety constantly threaten the health of consumers and the reputation of agricultural product brands. Quality and safety issues such as excessive pesticide residues, heavy metal pollution, and illegal additives are not uncommon, posing potential risks to consumers' physical health. For example, some vegetable growers excessively use pesticides in order to pursue yield and prevent pests and diseases, resulting in serious pesticide residues exceeding the standard in vegetables. Consumers who consume these vegetables may experience health problems such as food poisoning, leading to a crisis of trust in agricultural products. The reasons for the difficulty in ensuring the quality and safety of agricultural products are complex. The decentralized operation mode of agricultural production has increased the difficulty of supervision, making it difficult to comprehensively and effectively monitor the production process of every farmer. Some farmers have weak awareness of quality and safety, and in order to reduce costs and increase profits, they are willing to violate regulations by using banned pesticides and fertilizers.

1.3 Limited brand communication channels

In the era of information explosion, brand communication is crucial for the construction of agricultural product brands. At present, the channels for promoting agricultural product brands in China are relatively limited, and the communication methods are single, making it difficult to effectively reach the target consumers. Many agricultural product brands still rely on traditional offline sales channels, such as farmers' markets, supermarkets, etc., with insufficient development of online sales channels. Today, with the increasing popularity of the Internet, this single communication channel model makes it difficult for agricultural product brands to break through regional restrictions and expand market shares (Li, 2025).The main reasons for the limited dissemination channels of agricultural product brands are as follows. Agricultural product producers have weak awareness of brand communication, lack understanding of the importance of brand communication, and are unwilling to invest too much money and energy in brand communication. There is a shortage of professional talents in agricultural product brand communication, as well as a lack of professional brand planning, marketing, and promotion teams, resulting in poor brand communication effects. The construction of agricultural product brand communication platforms lags behind, lacking influential agricultural product e-commerce platforms and brand promotion platforms, making it difficult to form a joint force for brand communication.

1.4 Weak brand premium ability

Brand premium ability is one of the important indicators to measure the competitiveness of agricultural product brands. However, currently most agricultural product brands in China have weak premium capabilities, making it difficult to maximize brand value. Consumers often pay more attention to price factors when purchasing agricultural products, and have lower brand awareness and loyalty. Even some agricultural product brands with regional characteristics find it difficult to obtain high brand premiums in the market due to the lack of effective brand management and marketing promotion. The main reasons for the weak premium ability of agricultural product brands include insufficient investment in brand building, insufficient exploration of brand cultural connotations, and weak awareness of brand protection. The construction of

agricultural product brands requires long-term capital investment and continuous brand maintenance, but many agricultural product producers and enterprises have limited financial strength and are unable to afford the high costs of brand construction. The exploration of the cultural connotations of agricultural product brands is not deep enough, lacking unique brand stories and cultural heritage, making it difficult to resonate emotionally with consumers. The weak awareness of brand protection has led to the easy infringement of agricultural product brands by counterfeit and inferior products, which has damaged the brand image and consumer interests. The lagging construction of agricultural product brands seriously affects the competitiveness of the agricultural product market. To solve these problems, it is necessary for the government, enterprises, farmers and other parties to work together to strengthen the top-level design of agricultural product brand construction, increase investment in science and technology, improve the quality and safety level of agricultural products, expand brand communication channels, enhance brand premium ability, and promote the construction of agricultural product brands in China to a new level.

2.Exploration into the Root Causes of Lagged Brand Building in Agricultural Products

2.1 Self factors of agricultural production entities

As the micro foundation of brand building, the weak capabilities of agricultural production entities constitute the primary obstacle. Under the traditional small-scale farming model, decentralized production entities generally suffer from weak brand awareness. Most farmers still adhere to the mindset of “emphasizing yield over quality”, treating products as primary raw materials rather than brand carriers, and ignoring standardized production and quality control. Even among the new types of agricultural operators, cooperatives and family farms have the ability to produce on a large scale, but are limited by a lack of talent and technological shortcomings, and their brand operation capabilities are seriously inadequate. Taking agricultural product packaging as an example, most products still use simple woven bags or transparent plastic bags, which cannot reflect product characteristics and are difficult to form visual memory points. The low degree of organization of production entities further exacerbates the dilemma of brand building. Scattered farmers find it difficult to form a unified production standard and quality specification, resulting in uneven product quality in the same region. The contradiction between the “small production of thousands of households” and the “ever-changing market” has led to the awkward situation of “having products but no brand” in brand building. Even if some regions attempt to establish regional public brands, the lack of effective regulatory mechanisms often leads to the phenomenon of “free riding”, ultimately resulting in a loss of brand credibility.

2.2 Insufficient government support and services

The fragmentation of policy supply is a key factor restricting brand building. The current agricultural policy system still mainly relies on production subsidies, and the proportion of special funds for brand building is relatively low(Sun & Sun, 2023). Although some regions have established brand development funds, the efficiency of fund utilization is low, and there is a tendency to prioritize selection over cultivation. For example, a certain province has held the “Top Ten Agricultural Product Brands” selection activity for three consecutive years, but the award-winning products generally lack sustained support in subsequent market promotion, and the brand value has not been effectively transformed into market competitiveness. The imperfect public service system has exacerbated institutional barriers to brand building. The quality traceability system has not yet achieved full industry chain coverage, and there is a gap in standardized control of agricultural products from the field to the dining table. The lagging infrastructure of cold chain logistics has led to a high rate of loss of fresh agricultural products and a severe compression of brand premium space. Taking a major fruit producing area as an example, due to insufficient cold chain facilities, the loss rate of high-quality fruits during transportation is as high as 30%. The brand premium is difficult to cover the logistics cost, and the enterprise lacks branding motivation.

2.3 Market environment and changes in consumer demand

Under the background of consumption upgrading, the structural transformation of market demand poses higher requirements for brand building. The new generation of consumers not only focus on product quality, but also pay more attention to the cultural connotation and emotional value behind the brand. However, most agricultural product brands are still in the primary stage of “origin+category”, lacking differentiated positioning and value proposition. For example, among thousands of tea brands across the country, over 80% of brand names contain regional elements such as “mountain,” “peak,” and “cloud,” resulting in severe brand homogenization and difficulty in forming consumer awareness. The marketing challenges brought

about by channel transformation cannot be ignored. The rise of emerging channels such as e-commerce live streaming not only provides opportunities for agricultural product brands to overtake, but also intensifies the intensity of market competition.

3.The key role of traceability system in the construction of agricultural product brands

3.1 Ensure the quality and safety of agricultural products

The traceability system builds a new defense line for agricultural product quality and safety through the dual wheel drive of “production process visualization+quality standard digitization”. On the production end, intelligent sensors based on the Internet of Things can collect 12 environmental parameters such as soil moisture, temperature, and light in real time, and combine blockchain technology to form tamper proof production logs. Taking an apple planting base as an example, its traceability system recorded 36 key node data from flowering to harvesting period, and the qualified rate of pesticide residue detection increased by 28% compared to the traditional mode. The full monitoring of cold chain logistics in the circulation process has become the key to quality assurance. Through RFID tags and GPS positioning technology, temperature and humidity fluctuations during the transportation of agricultural products are accurately recorded, and a warning mechanism is triggered when the deviation exceeds $\pm 2^{\circ}\text{C}$. After a vegetable enterprise applied this technology, the product loss rate decreased from 15% to 5%, and the average annual economic loss was reduced by over 10 million yuan. This data-driven control mode shifts the quality and safety of agricultural products from end of pipe sampling to process control, forming a new pattern of “prevention first, full process supervision”.

3.2 Enhance consumer trust

The traceability system builds a trust bond between consumers and producers through the “one item, one code” technology. Consumers can obtain over 40 pieces of information, including planting environment, agricultural operations, testing reports, etc., by scanning the product traceability source code. After a certain rice brand launched a traceability experience activity, its repurchase rate jumped from 32% to 68%, and the mention rate of “safe and reassuring” in user reviews increased fourfold. This transparency mechanism effectively solves the dilemma of “information asymmetry” and shifts consumers from passive acceptance to active participation.

3.3 Promote the differentiated development of agricultural product brands

The traceability system provides technical support for the differentiation of agricultural product brands. By deeply mining production data, enterprises can build a multidimensional brand value system. A certain fruit brand has extracted quantitative indicators such as “sweetness value above 18°C ” and “sugar acid ratio of 35:1” based on traceability data, forming a unique quality label. This data-driven expression enables brands to stand out from homogeneous competition, with their single product premium ability being 40% higher than ordinary products. Cultural traceability has become a new path for brand differentiation(Wei, Li, & Huang, 2023). The traceability system not only records physical attributes, but also carries intangible values such as regional culture and planting traditions. A certain tea brand has incorporated “non legacy tea making techniques” into its traceability system, allowing consumers to scan the code to watch videos of inheritors making tea. This cultural empowerment has enabled the brand’s premium to break through traditional quality boundaries, with its limited edition products being auctioned at three times the price of similar products.

3.4 Promote the upgrading of agricultural industry

The digital transformation driven by the traceability system is reshaping the ecosystem of the agricultural industry chain. On the production side, the intelligent decision-making system optimizes the planting plan based on traceability data. After applying this technology in a vegetable base, the yield per unit area increased by 18% and the use of pesticides decreased by 22%. In the processing stage, traceability data guides grading and sorting. A fruit enterprise achieved premium gradient through quality grading, and the proportion of high-end products increased from 15% to 40%. The data assets generated by the traceability system provide possibilities for innovation in agricultural financial services. Banks can evaluate farmers’ credit based on traceability data. The “traceability loan” product launched by a certain rural commercial bank has a credit limit three times higher than the traditional model, and a non-performing loan ratio of less than 0.5%(Lu et al., 2024). This data-driven financial innovation effectively alleviates the problem of agricultural financing and accelerates the cultivation of

new business entities.

Table 1 Comparative analysis of the application effect of traceability system

Indicator Dimension	Traditional Model	Traceability System Model	Improvement Amplitude
Pesticide Residue Qualification Rate	72%	92%	+28%
Circulation Loss Rate	15%	5%	-10%
Consumer Repurchase Rate	32%	68%	+36%
Brand Premium Capacity	Baseline Value 1.0	1.4	+40%
Financial Credit Limit	500,000 yuan/household	1,500,000 yuan/household	+3 times

The development of traceability system is showing three major trends: technology integration is extending from a single link to the entire chain, application scenarios are expanding from quality and safety to value creation, and participating entities are shifting from government led to diversified collaboration. This transformation not only reshapes the underlying logic of agricultural product brand building, but also promotes the transition of agricultural economy towards digitization, branding, and greening.

4. Strategies for Building a Comprehensive Traceability System

4.1 Strengthen policy support and guidance

Policy supply needs to break through traditional subsidy thinking and shift towards systematic institutional design. It is suggested to establish a special fund for traceability system, which should account for 3% -5% of agricultural fiscal expenditure, with a focus on supporting the construction of infrastructure such as cold chain logistics nodes and data platforms. Policy incentives should focus on covering the entire industry chain. For enterprises that apply traceability technology, a 50% discount on value-added tax will be given upon collection; For regions that establish regional public traceability platforms, preferential treatment will be given to land indicators and project approvals. We need to establish a policy dynamic adjustment mechanism. According to the stage of technological development, the traceability system support policies are revised every two years, with a focus on cutting-edge technologies such as blockchain and artificial intelligence.

4.2 Improve technical standards and specifications

Technical standards need to establish a hierarchical system of “basic standards+application standards”. The basic standards should cover the entire process of data collection, transmission, storage, etc., such as the development of the “Agricultural Product Traceability Data Element Standard”, which unifies the format and coding rules of 32 core data items. The application standards need to develop differentiated specifications for different categories, such as adding quality indicators such as sugar content and acidity for fruits, and adding disease prevention and control information for livestock and poultry. The formulation of standards should establish a multi-party collaborative mechanism(Zhang & Qin, 2024). Led by the agricultural department, a standard committee is established in collaboration with research institutions, leading enterprises, certification bodies, etc. to ensure the scientific and practical nature of the standards.

4.3 Strengthen subject responsibility and participation

The production entity needs to establish a linkage mechanism of “quality traceability brand”. Deeply link traceability data with quality control, such as triggering a system warning if pesticide residue exceeds the standard, and adding it to the blacklist if there are three consecutive warnings. After implementing this mechanism, the qualified rate of brand agricultural product sampling in a certain cooperative increased from 89% to 98%, proving that responsibility binding can form effective quality constraints. The circulation subject should establish a collaborative system of “cold chain traceability distribution”. Using temperature sensors and GPS positioning technology to achieve full visualization of cold chain logistics. The practice of a logistics enterprise has shown that this technology can reduce the cold chain breakage rate from 15% to 2%, and reduce the consumer complaint rate by 63%, proving that technological empowerment can reshape the value distribution of the circulation link. A governance mechanism involving multiple parties needs to be established. Establish a traceability

committee composed of representatives from the government, enterprises, and consumers to regularly evaluate the operational effectiveness of the system.

Table 2 Comparative analysis of the application effect of traceability system

Indicator Dimension	Traditional Model	Traceability System Model	Improvement Amplitude
Pesticide Residue Qualification Rate	72%	92%	+28%
Circulation Loss Rate	15%	5%	-10%
Consumer Repurchase Rate	32%	68%	+36%
Brand Premium Capacity	Baseline Value 1.0	1.4	+40%
Financial Credit Limit	500,000 yuan/household	1,500,000 yuan/household	+3 times
Policy Support Intensity	0.5 billion yuan/year	2.3 billion yuan/year	+3.6 times

summary

The lagging construction of agricultural product brands is essentially a concentrated manifestation of the lack of quality trust system and the unsmooth market value transmission mechanism. The traceability system provides a systematic solution to the dilemma of agricultural product brand building by reconstructing the quality and safety assurance mechanism, reshaping consumer trust relationships, and reshaping the logic of brand value creation.

Funding

This research was supported by the Zhong Kai College of Agricultural Engineering Graduate Student Science and Technology Innovation Fund Grant (KJCX2024031) and General Program of the National Social Science Foundation (21BSH104). The funding institutions had no role in the study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Conflict of Interests

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

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Strategic Construction of the Technology Ecosystem in the Healthcare Industry: Synergistic Optimization of Innovation Policy, Organizational Agility and Talent Pool

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Abstract: This paper proposes a strategic framework for constructing the technological ecosystem in the healthcare industry based on complex adaptive systems theory, focusing on the tripartite collaborative optimization of innovation policies, organizational agility, and talent reserves. Innovation policies guide resource allocation and reduce systemic risks through classification tools, dynamic adaptation, and ethical calibration; organizational agility enhances technical responsiveness through structural flexibility, knowledge flow, and hybrid forms; talent reserves emphasize the dynamic calibration of skill graphs and intergenerational knowledge transfer. The study proposes a dynamic coupling mechanism and a risk resistance system to mitigate policy delays, break technical path dependence, and strengthen organizational resilience. This framework provides a governance path for the transition of medical technology from isolated breakthroughs to ecological development, with its methodology applicable to high-tech service industries.

Keywords: Medical Technology Ecosystem; Innovation Policy; Organizational Agility; Talent Reserve; Dynamic Coupling Mechanism

Published: Jun 23, 2025

DOI: <https://doi.org/10.62177/amit.v1i3.479>

1. Introduction

Under the dual impetus of digital transformation and population aging, the complexity of the medical industry's technology ecosystem has significantly increased. The optimization of a single element can no longer meet the demands for systemic innovation. This paper, based on the theory of complex adaptive systems, proposes a ternary synergy model involving innovative policies, organizational agility, and talent reserves. It aims to reveal the logic of resource allocation under policy guidance, the dynamic adaptive mechanisms of organizational structures, and the principles for constructing a matrix of talent capabilities. Through theoretical deduction and paradigm integration, it elucidates the nonlinear interactive relationships among the three elements, providing a strategic framework for the transition of medical technology from isolated breakthroughs to ecological development. The methodological significance of this approach can be extended to other high-tech service industries.

2. The theoretical basis of collaborative optimization

2.1 The guiding function of innovation policy

In the strategic construction of the technology ecosystem in the medical industry, the core role of innovation policy lies in

guiding resource allocation, shaping market expectations and reducing systemic risks. Its theoretical foundation can be deeply discussed from three dimensions: classification of policy tools, adaptability of technology life cycle and industry particularity.

2.1.1 Taxonomic analysis of policy tools

In the taxonomic analysis of policy tools, we can divide policy tools into three categories: mandatory, incentive and voluntary. Each type of policy tool has its specific application scenarios, which are suitable for different technological development stages and market environments, so as to meet diversified policy needs.

Mandatory tools, such as industry access standards and data security regulations, are usually applicable to high-risk areas such as gene editing technology and AI-assisted diagnosis. These tools ensure the ethical compliance of technology application through rigid constraints, thus protecting public interests and social stability.

Incentive tools, such as R&D tax credits and innovation funds, accelerate the commercialization of technology through economic incentives. Such tools are particularly effective in strategic areas such as domestic substitution of medical devices and promotion of new energy vehicles, which can stimulate market vitality and promote technological innovation and industrial upgrading.

Voluntary tools, including industry technology white papers and industry-academia-research alliances, rely on spontaneous collaboration among market entities. These tools are suitable for exploratory periods when technical routes have not yet been unified, such as in the field of digital therapeutics. Voluntary tools can facilitate knowledge sharing and resource integration, providing flexible exploration space for technological development.

The boundaries of these three types of policy tools are not fixed, and the division between them depends on the dynamic balance between technology maturity and social risk tolerance. With the progress of technology and social development, the classification and application of policy tools also need to be adjusted and optimized constantly to adapt to new challenges and needs.

2.1.2 Policy flexibility from the perspective of technology life cycle

In different stages of the technology life cycle, the evolution of medical technology presents significant stage characteristics, which requires policies to have the ability to dynamically adjust to meet the needs of technological development:

In the budding stage (for example, in the early stages of mRNA vaccine research), a relaxed “regulatory sandbox” policy is needed to allow trial and error and innovation, thus providing enough space for the development of new technologies;

In the growth period (such as medical robot field), we need to take into account standardization and intellectual property protection, ensure the healthy development of technology, and avoid excessive regulation that hinders technological progress;

In the mature stage (such as traditional imaging equipment), policies should shift to cost control and inclusive measures to ensure the widespread application and popularization of technology. The core of policy flexibility lies in accurately matching the nonlinear development pattern of technological innovation through institutional design, thereby promoting continuous technological progress and sustainable social development.

2.1.3 The tension between ethics and efficiency in the medical industry

In the medical industry, the particularity of technology lies in its direct connection with life and health, the most fundamental human value. Therefore, in policy design, both ethical security and innovation efficiency must be considered at the same time: The requirement of ethical priority means that a strict transparent review mechanism must be established for AI diagnostic algorithms, the use of patient data and other aspects to ensure the ethical safety of technology application;

The need for efficiency requires simplifying the approval process of clinical trials so that the transformation and application of medical technologies can be accelerated. The inclusiveness of policies is reflected in the release of the vitality of medical innovation under the premise of ensuring controllable risks through hierarchical and classified management methods (for example, different regulatory strategies for breakthrough therapies and improved technologies).

To sum up, the theoretical value of innovation policy lies in its function as a “system regulator” - through tool combination, dynamic adaptation and ethical calibration, it constructs a sustainable channel for medical technology from research and development to application, and provides institutional guarantee for the synergy of organizational agility and talent reserve.

2.2 Analyze the core of organizational agility

In today's healthcare industry technology ecosystem, the dynamic nature of the environment demands that organizations not only have the ability to respond quickly to external changes but also achieve self-adjustment and adaptation in their organizational structure. The core theory of organizational agility can be deeply analyzed from three dimensions: spatial-temporal duality, threshold effects of knowledge flow, and complementary structural forms, thereby revealing its central role in the process of technology diffusion and application.

2.2.1 Dual dimensions of agility: structural flexibility (space) and iteration speed (time)

Organizational agility is essentially an organic combination of spatial flexibility and temporal efficiency:

Structural flexibility is primarily reflected in the reconfigurability of organizations in space. Taking medical research institutions as an example, to adapt to the development of cutting-edge technologies such as gene therapy and digital twins, these institutions need to break down barriers between traditional departments and form interdisciplinary project teams (such as collaborative groups of bioengineers and clinicians) to quickly align with technical requirements. The core of flexible structures lies in modular design concepts (for instance, adopting a "platform + small teams" model), which allows resources to be flexibly allocated according to actual needs and enables low-friction reorganization.

Iterative speed focuses more on the efficiency of learning-action cycles over time. Given the rapid evolution of medical technology (such as weekly updates in diagnostic algorithms by artificial intelligence), organizations need to compress decision-making levels and establish a closed-loop mechanism of "test-feedback-optimization." Through this mechanism, organizations can quickly validate the feasibility of new technologies, for example, through pre-research projects, and then adopt phased reviews to replace traditional linear management methods, thus avoiding missing the optimal timing for technological development due to over-planning.

2.2.2 Threshold effect of knowledge flow efficiency and organizational learning ability

In the field of medical technology, knowledge flow has become the basic support for organizational agility due to its high complexity. This support is reflected in many aspects, especially for the improvement of organizational learning ability and the transformation of technological innovation.

The so-called threshold effect refers to the phenomenon in knowledge sharing where, when the density of knowledge sharing falls below a certain critical value, such as insufficient communication frequency among cross-domain experts, an organization's learning capacity will suffer a severe blow, leading to a cliff-like decline. This decline directly results in the lag of technology transfer, affecting the overall innovation efficiency of the organization. Conversely, if high-frequency knowledge interaction can be achieved, for example, clinical data being fed back to the R&D team in real time, it can trigger what is known as a "cognitive leap." This cognitive leap will significantly accelerate technological iteration and innovation.

To achieve efficient knowledge flow, organizations need to rely on two main mechanisms:

The first is the explicit mechanism, which greatly reduces the cost of knowledge decoding by establishing standardized medical record database, technical roadmap and other tools. In this way, the transmission and understanding of knowledge become more efficient, thus improving the learning efficiency of the whole organization.

The second is the implicit transformation mechanism, which usually plays a role in informal scenarios, such as mentorship system, case discussion, etc. In these informal exchanges, experiential knowledge is transmitted and shared, thus promoting the flow and accumulation of knowledge within the organization.

2.2.3 Complementarity between hierarchical system and network structure

In the process of medical technology diffusion, it is necessary to balance control and innovation freedom, which requires us to mix the design of organizational form to achieve the best effect:

Hierarchical system can play its stability advantage in the stage of technical standardization (such as mass production of medical devices), and ensure the quality and compliance of products through a clear chain of rights and responsibilities;

The network structure is more suitable for the technology exploration period (such as the development of new biomarkers), which relies on the flat collaboration mode to stimulate innovation. The complementarity of these two structures is mainly reflected in:

Dynamic switching: for example, when a large hospital is carrying out routine diagnosis and treatment activities, it will

maintain the stability of the hierarchical system, while when it is carrying out scientific research, it will activate temporary project teams to adapt to different work needs;

Interface integration: By setting up hub institutions such as “innovation committee”, conflicts between hierarchical decision-making and networked execution can be coordinated to achieve effective integration between the two.

3.Implementation path of strategy construction

3.1 Design of dynamic coupling mechanism

In the strategic construction of the technology ecosystem in the healthcare industry, establishing a dynamic coupling mechanism is crucial. The purpose of this mechanism is to achieve organic synergy among the three key elements: innovation policy, organizational agility, and talent reserve. Through such mechanism design, it can effectively address the time lag issues that arise during system operation, realize dynamic matching between elements, and maintain the stable development of the entire system.

3.1.1 Policy signal and organizational response time lag mitigation strategy

In the medical technology ecosystem, there is often a significant time lag between policy formulation and organizational response, which has a significant negative impact on the efficiency of technological innovation. In order to effectively eliminate this time lag problem, we need to build a series of mechanisms:

Forward-looking policy early warning system: Through technical prediction and demand analysis, the development trend of medical technology can be predicted in advance to ensure that policy formulation is forward-looking, so as to reduce the gap between policy and actual demand.

Rapid response channel: Establish a green channel at the policy implementation level, such as setting up a rapid approval mechanism for medical technology innovation, so as to shorten the time from policy formulation to implementation and speed up the response speed of organizations to policies.

Feedback regulation loop: build a real-time monitoring system for policy effects, adjust policy parameters in time through big data analysis, and ensure that policies can be dynamically adjusted according to actual conditions, so as to improve the adaptability and effectiveness of policies.

3.1.2 Dynamic calibration methodology of talent skill map and technology roadmap

With the rapid development of medical technology, talent skills and technical needs must evolve in sync, which requires us to establish a dynamic calibration mechanism:

A talent forecasting model driven by technology roadmap: By analyzing the development roadmap of medical technology, we can predict the skill requirements for key positions in the next 3-5 years, thus providing forward-looking guidance for talent development.

Talent training system: In order to adapt to the changing medical technology environment, we need to establish a modular, scalable continuing education system to support the continuous updating and improvement of medical staff skills.

Collaborative mechanism of industry-education integration: By promoting cooperation between medical institutions, universities and enterprises to jointly build a talent training platform, seamless connection between talent demand and supply can be realized, and talent development and technological progress can be synchronized.

3.1.3 Three-element balance control model based on negative feedback regulation

In order to ensure the steady development of medical technology ecosystem, it is necessary to build a mechanism based on negative feedback regulation to realize the self-regulation and optimization of the system:

System status monitoring index system: This part involves the design of a comprehensive evaluation system, covering multiple key dimensions, such as policy adaptability, organizational agility, talent matching, etc., to comprehensively monitor and evaluate the operation status of the medical technology ecosystem.

Dynamic balance algorithm: In this link, the principles and methods of system dynamics will be used to construct a mathematical model to describe and analyze the interaction and influence among the three elements (policy, organization and talent), so as to realize the accurate simulation and prediction of the dynamic balance of the system.

Regulatory intervention strategy library: In order to deal with various possible imbalances, a series of regulatory strategies

should be formulated in advance, including policy fine-tuning, organizational restructuring, personnel retraining and other strategies, so as to intervene quickly and effectively in actual operation.

Through the implementation of this dynamic coupling mechanism, real-time monitoring, intelligent prediction, and precise regulation of the medical technology ecosystem can be achieved. This not only significantly enhances system operational efficiency but also promotes the coordinated development of innovative policies, organizational agility, and talent reserves, ultimately driving the sustainable development of medical technological innovation. The mechanism particularly emphasizes the system's adaptability, ensuring that the healthcare industry can flexibly and effectively address various challenges brought about by technological changes.

3.2 Strengthening risk resistance

To ensure the robust development of the healthcare industry's technology ecosystem, it is crucial to build a multi-level risk resistance system. This system must start from three key dimensions: technological pathways, organizational structure, and talent succession, working together to construct a systematic risk management mechanism to address various potential challenges and uncertainties.

3.2.1 Breaking the technical path dependence and reserving redundant resources

In the process of medical technology development, we often encounter the dilemma of path dependence, which requires us to establish a double safeguard mechanism to ensure the diversity and sustainability of technology development:

Diversified technology route layout: In key areas of the medical industry, such as cancer treatment, multiple technology routes such as immunotherapy, targeted therapy and gene editing should be supported simultaneously to avoid over-reliance and lock-in on a single technology.

Innovative fault tolerance mechanism: In order to encourage innovation and support the early development of exploratory technologies, special venture funds can be set up to reserve necessary space and resources for possible failures, thus reducing the risks in the innovation process.

Technical monitoring and early warning system: By establishing a technology maturity assessment model, it can timely identify those technical routes that may be overturned or replaced by new technologies, so as to make preparations in advance and reduce the impact of technological change.

3.2.2 Dialectical management of organizational memory and change tension

Organizations need to maintain a dynamic balance between inheritance and innovation:

Knowledge sedimentation mechanism: solidify organizational memory through digital medical record system, diagnosis and treatment plan database and other forms

Innovation incubator: Set up an independent innovation department outside the traditional structure to protect transformative ideas from existing processes

Cultural adjustment strategy: carry out organizational change workshops regularly to promote cultural transformation step by step and reduce resistance to change

3.2.3 Institutional arrangements for intergenerational knowledge transfer of talents

The risk of talent gap needs to be systematically designed:

Mentor-apprentice system: senior experts are required to train successors, and the effectiveness of training is included in performance appraisal

Knowledge graph construction: transform implicit experience into standardized diagnosis and treatment decision tree and operating procedures

Intergenerational integration platform: set up cross-age group projects to promote the collision and integration of experience and innovative thinking

This risk resistance system builds the resilience foundation of the medical technology ecosystem through diversified technological deployment, innovative transformation of organizational memory, and institutional inheritance of talent knowledge. These three dimensions support each other: technological diversity provides options for organizational change, management of organizational memory ensures the continuity of knowledge transmission, and the construction of a talent

pipeline offers sustained impetus for technological innovation. This systematic approach to risk control can effectively enhance the healthcare industry's ability to cope with various risks such as technological disruption, policy adjustments, and market fluctuations, ensuring the sustainable development of the technology ecosystem.

4. Conclusions

The strategic construction of the medical technology ecosystem is essentially about stimulating collaborative emergence behaviors among organizations and talents through institutional design. This paper argues that when policies are forward-looking, organizations develop dual capabilities, and talents form a T-shaped composite structure, the system will exhibit exponential innovation efficiency. Future research should focus on the dynamic changes in the weights of these three elements, especially the reorganization logic during technological paradigm revolutions and discontinuous innovation scenarios. This theoretical framework not only expands the boundaries of medical management research but also provides a new governance perspective for achieving technological inclusiveness and health equity.

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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Research on the Synergistic Mechanism of Strategic Innovation and Technological Progress —— An Empirical Analysis Based on the Organizational Performance of the Medical Industry

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Abstract: This study systematically explores the theoretical framework and practical pathways of the synergy mechanism between strategic innovation and technological progress in the healthcare industry. The research finds that the strong regulatory nature, long R&D cycle, and multi-party participation of the healthcare industry give rise to a unique characteristic of “dynamic equilibrium under constraints” in its synergy mechanism. A theoretical model is constructed, encompassing three dimensions of strategic innovation (disruptive, open, ecological), three types of technological progress (breakthrough, incremental, integrative), and three levels of synergy mechanisms (element coupling, dynamic adaptation, value co-creation). Based on the theories of innovation ecosystems, technology tracks, and dual organizational capabilities, an analytical framework combining macro, meso, and micro perspectives is formed. The study also reveals coordination barriers faced by the healthcare industry, such as intellectual property barriers, policy lag, and coordination costs, providing a systematic solution to the “innovation island” dilemma.

Keywords: Strategic Innovation; Technological Progress; Collaborative Mechanism; Medical Industry; Organizational Performance

Published: Jun 23, 2025

DOI:

1.Introduction

This study explores the mechanism by which strategic innovation and technological progress in the healthcare industry jointly drive organizational performance. Based on dynamic capability theory, a “strategy-technology-performance” analytical framework is constructed to reveal the synergistic paths between the two under special medical circumstances. The findings indicate that strategic innovation provides direction and resources for technology application, while technological progress enhances the effectiveness of strategy implementation. Their synergy can overcome the limitations of individual innovations. The strong regulation and long cycles characteristic of the healthcare sector make the synergistic mechanism exhibit features of “dynamic equilibrium under constraints,” necessitating a balance between innovative breakthroughs and robust compliance. This research offers theoretical guidance to address the issue of “innovation silos” in the healthcare field, suggesting the need to strengthen both strategic flexibility and technology absorption capabilities to build an ecosystem for continuous innovation. For policymakers, it is essential to optimize the institutional environment to promote synergy; for healthcare managers, a dynamic matching mechanism for technology foresight and strategic adjustment should be established.

2.The theoretical framework for the synergy between strategic innovation and technological progress

2.1 Definition of core concepts

The system analyzes the synergistic mechanism between strategic innovation and technological progress in the healthcare industry. Healthcare organizations achieve systemic transformation by reconstructing their diagnostic and treatment systems, integrating resources, and building collaborative networks through various types of innovation. Technological progress is characterized by stepwise development, encompassing breakthrough, incremental, and convergent technologies, which collectively form the healthcare technology innovation system. These two dimensions work in synergy through dynamic coupling mechanisms, including element coupling, process adaptation, and value co-creation, forming a dual-driven model. This model adapts to the characteristics of the healthcare industry, providing theoretical support for the healthcare innovation system and revealing the dialectical relationship between strategy and technology, offering a framework for sustainable development in healthcare institutions^[1].

2.2 Theoretical basis of the coordination mechanism

A multi-level theoretical framework has been constructed, integrating the theories of innovation ecosystems, technology tracks, and organizational dual capabilities to explain strategic innovation and technological progress in the healthcare industry. The theory of innovation ecosystems illustrates how diverse entities build innovation networks, forming an ecological chain from research and development to application. The theory of technology tracks analyzes path dependence and breakthroughs in the evolution of medical technologies, emphasizing the importance of technology planning and organizational design. The theory of organizational dual capabilities elucidates how healthcare institutions balance innovation and optimization, adjusting strategies according to the environment. These theories complement each other, providing a structural foundation, dynamic evolution patterns, and implementation effectiveness for innovation in the healthcare industry, forming a systematic theoretical tool to help healthcare organizations achieve high-quality development amid rapid technological iterations and policy changes^[2].

2.3 Analysis of collaborative characteristics in the medical industry

The healthcare industry, as a technology-intensive and heavily regulated sector, exhibits unique complexities in its strategic innovation and technological advancement synergy mechanisms. The high regulatory environment not only restricts the freedom of innovation but also promotes technical standardization; long R&D cycles require organizations to have long-term capability reserves; while the multi-party innovation ecosystem faces coordination challenges, it also facilitates resource complementarity and value co-creation. These characteristics necessitate that the healthcare synergy mechanism seeks balance under multiple constraints. At the same time, the synergy process in the healthcare industry encounters obstacles such as intellectual property protection, policy lag, technological development gaps, and high inter-organizational cooperation transaction costs. These obstacles interact, forming a “synergy dilemma” in healthcare innovation. The industry’s uniqueness and synergy barriers reinforce each other, requiring healthcare organizations to adopt a systemic approach when building synergy mechanisms, balancing innovation with risk management to achieve sustainable high-quality development^[3].

3.The mechanism of strategic innovation and technology progress coordination mechanism

3.1 Synergistic path at the strategic orientation level

In the healthcare industry, strategic innovation and technological progress achieve synergies through the critical path:

3.1.1 Technology foresight and strategic goal matching mechanism

The strategy of medical organizations needs to be based on technology trends. The matching mechanism includes:

Forward-looking Technology Assessment: Scanning the clinical application potential of emerging technologies to inform strategic planning. For example, hospitals assess how quantum computing can enhance drug development efficiency. Strategic Goal Decomposition: Transforming macro-strategies into specific technical solutions. For instance, breaking down the goal of improving diagnostic accuracy into introducing AI diagnostic systems and building a gene testing platform. Dynamic Adjustment Mechanism: Establishing a strategic-technical feedback loop to regularly evaluate the alignment between

technology implementation outcomes and strategic goals, and promptly adjust the ^[4].

3.1.2 Two-way reinforcement of dynamic capability construction

The coordinated development of strategic flexibility and technology absorption ability is the core power of continuous innovation of an organization:

The strategic value of technology absorption capability: including the ability to identify external technological value, digestion and integration capabilities, and commercial application capabilities. These capabilities influence the depth and breadth of strategic innovation. The technical support for strategic flexibility: the organization's ability to quickly adjust its strategic direction, which relies on modular technical architecture, cross-departmental collaboration mechanisms, and agile management processes.

Two-way strengthening mechanism: the enhanced technology absorption ability enables the organization to respond to the technological changes required by strategic adjustment more quickly; at the same time, the strategic flexibility provides institutional guarantee for technology absorption.

This kind of synergy is essentially to achieve a virtuous cycle of organizational innovation ecology by establishing a technology-driven strategic decision-making system and a technology development path led by strategy. The medical industry needs to emphasize the balance of innovation under the compliance framework, avoid policy risks caused by technological adventurism, and prevent technological lag caused by strategic conservatism^[5].

3.2 Synergy mode at the level of resource integration

In the medical industry, the synergistic mode of resource integration is very important. It not only breaks through the limitations of traditional resource allocation, but also realizes synergistic effect through systematic integration. This part will discuss two core synergistic modes.

The first is the systematic construction of the knowledge sharing platform, which is evolving from one-way transmission to multi-subject interaction. The collaborative value is reflected in three dimensions:

Data interoperability architecture: Establish a cross-institutional data platform to realize standardized docking of different data. For example, using federal learning technology to realize joint modeling of multi-party medical image data under the premise of privacy protection.

Knowledge transformation mechanism: Establish a transformation chain from basic research to clinical application. The discovery of scientific research institutions can be quickly transmitted to pharmaceutical companies through the platform, and clinical feedback can guide basic research^[6].

Collaborative innovation network: to form a problem-oriented distributed innovation community. For specific diseases, hospitals, enterprises and scientific research institutions can achieve precise matching of innovation elements through the platform.

3.2.2 Dynamic formation of complementary resource pool

Resource collaboration in the healthcare industry has evolved into a deeply complementary ecosystem:

Property collaboration model: Patent alliances reduce innovation barriers through cross-licensing, such as the construction of patent pools in the field of genetic testing, and accelerate technology standardization. Joint laboratories realize the intensive use of equipment, talents and funds, and integrate clinical resources, algorithm capabilities and theoretical research.

Talent flow mechanism: Establish a system to promote the flow of talents among industry, university and research institutes. Clinical doctors participate in R&D to ensure product applicability, engineers stay in hospitals to improve the efficiency of technology implementation, and researchers rotate in clinical practice to enhance problem orientation. Flow promotes the transfer of explicit knowledge and the exchange of tacit experience.

Risk sharing system: R&D risks are dispersed through innovation consortia. In the research and development of major medical equipment, hospitals define the needs, enterprises lead the development, and insurance institutions provide risk protection to form an innovation investment mechanism.

3.3 Dynamic evolution of collaborative mechanism

In the medical innovation ecosystem, strategic innovation and technological progress show complex dynamic evolution

characteristics, including gradual adaptation and breakthrough change. The synergistic mechanism is reflected in two aspects:

3.3.1 Feedback loop of technology iteration and strategic adjustment

Medical technology progress and strategic innovation interact:

Technology-driven strategic evolution: When new technologies accumulate to a certain extent, they promote the restructuring of strategic frameworks. For example, 3D bioprinting technology has prompted hospitals to move towards precision medicine.

Strategy leads technology development: forward-looking strategy guides the direction of technology research and development. After a medical group implements the smart hospital strategy, it invests in Internet of Things, big data and other technologies to form a closed loop.

Dynamic balance mechanism: establish a feedback system of monitoring, evaluation and adjustment. The key links include technology maturity assessment, strategic adaptability analysis and resource allocation flexibility.

3.3.2 Critical point mechanism of nonlinear synergistic effect

The co-evolution of the medical industry presents nonlinear characteristics:

Leap from quantitative to qualitative change: when variables such as technical performance, policy environment and market demand break through the critical value, a fundamental change in the strategic paradigm is triggered. For example, when the accuracy of AI diagnosis exceeds 95% and is recognized by regulations, hospitals will turn to an AI-first strategy.

Path dependence and breakthrough: the formation of inertia constraints in the existing technology system may create a strategic window period when disruptive technologies emerge. Organizations need to identify turning points, such as predicting the timing of transformation through technology road maps.

Compound effect amplification: The cross-fusion of different technology fields generates exponential innovation opportunities, which requires the strategic system to have the ability of portfolio management. It is necessary to establish a technology correlation analysis matrix to identify the technology portfolio with strategic synergy potential.

4. The impact path of the collaborative mechanism on the performance of medical industry organizations

4.1 Pathways to improve innovation performance

In the innovation ecosystem of the healthcare industry, the synergy between strategic innovation and technological progress plays a multifaceted role in enhancing organizational innovation performance. This impact primarily unfolds through two key pathways: paradigm shifts in R&D and the realization of intellectual property value, jointly driving medical organizations to improve their innovation efficiency from basic research to clinical translation^[7].

4.1.1 Paradigm optimization of R&D efficiency

The synergy mechanism significantly improves the efficiency of medical innovation:

Application of intelligent technology tools: The introduction of artificial intelligence and big data technologies, machine learning algorithms to rapidly screen drug candidate molecules, and preclinical research cycles from years to months; digital twin technology to build virtual patient models, reducing clinical trial costs. These technologies shift research and development from experience-driven to data-driven.

Construction of interdisciplinary collaboration platform: Under the guidance of open innovation, hospitals, universities and enterprises establish joint R&D centers to share resources and achieve seamless connection. For example, cancer hospitals cooperate with gene sequencing companies to improve the efficiency of targeted drug research and development by more than 40%.

Introduction of agile management method: Medical R&D projects adopt the concept of iterative development, set up independent test-feedback cycle, and avoid the risk of late rework in traditional R&D^[8].

4.1.2 Deep expansion of the patent value chain

Collaborative mechanism to improve the quantity and quality of patents, and reshape the commercial value of medical intellectual property rights:

The patent layout oriented by clinical needs ensures technological innovation and market application. This model reduces the

patent dormancy rate, such as the patent conversion rate of a cardiovascular device enterprise increased to 68%.

Build a patent portfolio, including core technologies, supporting processes and clinical application methods, and obtain sustained revenue through patent licensing. For example, the three-level protection system in the field of minimally invasive surgical instruments.

The application of digital technology creates new channels for patent value realization. For example, blockchain technology ensures the credibility of patent traceability, smart contract automatically settles authorization fees, and big data analysis matching technology matches supply and demand. These innovations reduce the cost of patent transaction by more than 30%. The deeper value of innovative performance improvement lies in changing the measurement dimensions: shifting from the scale of R&D investment to the intelligence level of innovation processes; from pursuing the number of patents to the ecological operation of intellectual property. Collaboration in the healthcare industry must be based on ethical review and quality control, demonstrating robust innovation characteristics. In the future, as frontier technologies mature, the synergistic mechanism's role in promoting innovation performance will be exponentially amplified.

4.2 Operation performance optimization path

The medical industry improves its operational performance through strategic innovation and technological progress, mainly in the process efficiency innovation and risk management system reconstruction:

4.2.1 Intelligent process reengineering of the whole value chain

Build an intelligent operation system: introduce Internet of Things and blockchain technology to realize the whole process traceability of drugs. Intelligent prediction algorithm improves the inventory turnover rate by more than 30% and reduces drug loss.

Digital reshaping of clinical pathways: integrating electronic medical records and other information systems to establish closed-loop management of diagnosis and treatment processes. The intelligent scheduling system reduces preoperative waiting time by 25%.

Dynamic optimization of resource scheduling: Bed management system based on 5G and edge computing, realizing intelligent redistribution of bed resources, and improving the utilization rate of beds by 8-12 percentage points.

4.2.2 Technology-enabled three-dimensional risk control system

Build a real-time monitoring and early warning network: using AIoT technology to achieve millisecond response of medical quality monitoring matrix. Automatic emergency plan is triggered by abnormal data to shorten the time of discovering medical adverse events.

Flexible design strategy redundancy: form a double-layer drug reserve structure to ensure the stability of drug supply and respond quickly to breakthrough therapies. Show advantages in public health emergencies.

Forward-looking risk modeling: Establish a medical accident risk prediction model by combining big data and machine learning. Analyze dispute cases, identify risk sources, and improve the incidence of medical disputes by 40%.

4.3 Social performance expansion path

The amplification effect of the synergy mechanism on the social value of medical organizations is realized through two strategic channels: brand building and industry influence:

4.3.1 Brand premium of technology-strategy synergy

Differentiated value proposition shaping: The hospital deeply integrates advanced technology applications (such as proton therapy) with its distinctive strategic positioning (specialized in oncology), establishing a brand perception of "technical expertise" in patients' minds. A specialized hospital increased the proportion of high-end patients by 15% through the dissemination of cases involving da Vinci robotic surgery.

Brand spillover of innovation ecology: When leading the formation of cross-regional medical consortia, technological innovation capability is taken as the core attraction. By exporting intelligent diagnosis and treatment systems and management standards, a positive cycle of "technology brand-strategic alliance-market expansion" is formed, with an annual growth rate of cooperative institutions reaching 20%.

4.3.2 Strategic contention for the right to set standards

Standard embedding of patent portfolio: strategically submit proprietary technology patents (such as medical image compression algorithm) to industry standard organizations, making them the optional solution for international standards such as DICOM. An enterprise has entered the CT equipment standard system through 5 core patents, and the annual patent fee is over 30 million yuan.

Promoting network of alliance standards: Establishing technology promotion alliances with upstream and downstream enterprises to accelerate the penetration of standards through multiple channels such as clinical demonstration and continuing education. In DRGs payment reform, the cost accounting standards for diseases led by leading hospitals have become a reference template for many medical insurance bureaus.

5. Conclusions

This study explores the impact of the synergy between strategic innovation and technological progress in the healthcare industry on organizational performance, revealing the dynamic interaction patterns and practical value between them. The research indicates that strategic innovation guides technological progress and provides resources, while technological progress offers means and efficiency support for strategic innovation. Their synergy significantly enhances performance. The study constructs a “strategy-technology-performance” framework, emphasizing the characteristic of “dynamic equilibrium under regulatory constraints” in the synergy mechanism of the healthcare industry, which requires maintaining strategic foresight and ensuring the robustness of technology application. In practice, effective synergy mechanisms enhance performance by accelerating the conversion of R&D results, optimizing resource allocation, and strengthening brand influence. The study also highlights the moderating role of policy environment and organizational culture in the synergy effect. For healthcare institutions, the study recommends avoiding extreme tendencies in digital transformation, establishing a calibration mechanism between technology roadmaps and strategic planning, and making forward-looking layouts in frontier areas. Future research can explore differentiated paths for building synergy mechanisms in different healthcare institutions and integration models of international technology cooperation with local strategic innovation. This study provides a theoretical and practical framework for the healthcare industry to overcome the “innovation island” dilemma.

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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Digital Protection and Inheritance: the Modern Way of Protecting Cangyuan Rock Painting

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Abstract: The Cangyuan rock painting, a precious prehistoric cultural heritage in southwestern China, document the social, economic, and spiritual life of the frontier ancestors from 3800 to 2700 years ago. With the rapid advancement of digital technology, the conservation efforts for the Cangyuan rock painting are transitioning from traditional methods to digital approaches. This article systematically reviews the historical value and current research status of the Cangyuan rock painting, delves into the practical applications of digital recording technologies, explores innovative models of digital technology in the protection and inheritance of rock painting, and proposes strategies to address the challenges currently faced in conservation efforts. The study shows that digital technology not only provides new methods for the scientific preservation of the Cangyuan rock painting but also opens up new pathways for the revitalization and utilization of cultural heritage, offering significant insights for the global conservation of rock art heritage.

Keywords: Cangyuan Rock Painting; Painted Rock Paintings; Cultural Heritage Revitalization; Digital Recording and Preventive Protection

Published: Jun 23, 2025

DOI: <https://doi.org/10.62177/amit.v1i3.480>

1.Introduction: Cultural value and protection challenges of Cangyuan rock painting

The Cangyuan rock painting, located in Cangyuan Wa Autonomous County, Lincang City, Yunnan Province, are primarily found on the rock faces of the Lancang River Basin. They are among the oldest and best-preserved rock paintings discovered in China to date. On June 25,2001, the State Council designated them as a national key cultural relic protection unit, marking their significant status within the national cultural heritage system^[1].

The Cangyuan rock painting include over 1,200 identifiable images, primarily depicting feathered, horned, tailed, and eared figures, which make up 74% of the total images^[2]. The paintings also feature animals such as cattle, monkeys, bears, elephants, and wild boars, as well as symbols like tree houses, villages, the sun, the moon, bows, and spears. These images depict activities such as hunting, warfare, rituals, nesting, migration, funerals, and music and dance^[3]. These images provide a rare and comprehensive record of the societies and spiritual world of the ancestors in the prehistoric southwestern border region, offering important archaeological evidence for studying ancient ethnic exchanges, diffusion history, religious, and cultural and artistic history in southwestern China and the Lancang-Mekong River Basin countries^[4].

However, for over 2,000 years, the Cangyuan rock painting have faced dual threats from natural weathering and human destruction. Over time, the patterns have become increasingly blurred. The old folks used to say that ‘the colors of the

Cangyuan rock painting would change with the time of day, weather conditions, and temperature, changing three times a day: red in the morning, pale by noon, and purple in the evening,' but this seems to be a legend. Among the 15 rock painting sites, only a few still retain relatively clear images; most have become indistinct, with some eroded by natural weathering, others severely damaged by human activities, and some completely lost^[5].

Faced with this severe situation, traditional conservation methods are no longer sufficient to meet the long-term preservation and research needs of the Cangyuan rock painting. Since 2018, under the support and guidance of the Cultural Heritage Administration and the Yunnan Provincial Cultural Heritage Administration, the Yunnan Provincial Institute of Cultural Relics and Archaeology has collaborated with over ten domestic and international universities and research institutions to conduct systematic surveys, documentation, and digital protection of the Cangyuan rock painting^[6]. This project marks a significant shift in the conservation efforts for the Cangyuan rock painting from traditional methods to digital means, offering new ideas and practical examples for the global conservation of rock art heritage^[7].

2. Technical practice of digital recording of Cangyuan rock painting

The digital preservation of the Cangyuan rock painting began in 2018, led by the Yunnan Provincial Institute of Cultural Relics and Archaeology, in collaboration with over a dozen universities and research institutions from China and abroad. This comprehensive project adopted an interdisciplinary approach, integrating advanced methods from archaeology, chronology, materials science, and digital technology, laying a solid foundation for the scientific preservation and in-depth study of the rock painting^[8].

2.1 High precision dating technology

Determining the absolute age of the Cangyuan rock painting is crucial for understanding their cultural significance and historical value^[9]. The project team used uranium-series dating, an internationally recognized method for dating rock art, to systematically analyze 68 samples from 8 representative sites of the Cangyuan rock painting^[10]. This method calculates the formation age of the sediment by measuring the ratio of uranium and its decay products in the secondary carbonate deposits covering the rock art, thereby determining the time frame in which the rock art was created. The primary advantage of this method is its ability to directly date the rock art itself, without relying on indirect evidence from nearby archaeological sites^[11].

The research findings indicate that the Cangyuan rock painting span from 3800 to 2700 years ago, suggesting that the tradition of painting these rock painting in this region lasted approximately 1100 years^[12]. This discovery not only fills a gap in the chronology of Cangyuan rock painting but also provides valuable insights into the relationship between the rock art traditions of southwestern China and Southeast Asia. Notably, the content of the rock painting exhibits distinct characteristics of different periods, showing similarities with some rock paintings in Southeast Asia, suggesting that the artists may have had interactions with ethnic groups in South China and Southeast Asia^[13].

2.2 3D scanning and digital modeling

To address the threats of natural weathering and human destruction to the Cangyuan rock painting, the project team employed high-precision 3D scanning technology to comprehensively document the murals^[14]. This technology captures 3D point cloud data of the rock painting's surfaces using laser or structured light scanning, and then generates high-resolution digital models through specialized software. Compared with traditional photography, 3D scanning not only captures the flat image information of the rock painting but also accurately records their surface morphology and texture details, including patterns that have become blurred due to weathering^[15].

The completed 3D model not only captures the current state of the rock painting but also enhances the visibility of the patterns through computer processing, aiding researchers in identifying the already blurred image details. As Wu Yun, the project leader, stated, "We conducted a 3D scan of the Cangyuan rock painting to document this precious cultural heritage as soon as possible." Currently, only Point 1 of the Cangyuan rock paintings is open to visitors, and the digital records provide a virtual display for the other unopened points^[16].

2.3 Pigment analysis and site survey

In addition to the digital documentation of the rock painting, the research team also conducted a scientific analysis of the

pigment composition used in these paintings. By analyzing the pigments from the rock painting and related cultural layers, researchers gained insights into ancient painting techniques and the sources of materials. This information is crucial for the preservation and restoration of the rock painting and provides clues to understanding the technological capabilities and cultural exchanges of prehistoric humans^[17].

Meanwhile, the team conducted a systematic archaeological survey of the area where the Cangyuan rock painting are located. They created a topographic map showing the distribution of the rock painting and related sites, and discovered new rock art sites in the basin of the Xiaohai River and its tributaries, as well as surrounding prehistoric sites. These efforts place the rock painting within a broader cultural context, aiding in the understanding of the living environment and social organization of the artists^[18].

The digital documentation work also emphasizes integrating with the oral histories of local ethnic minorities. The research team has conducted oral history recording studies for the Wa ethnic group and other local ethnic groups, collecting folk legends and memories about rock painting. This ‘living’ documentation not only enriches the cultural significance of the rock painting but also provides vivid narrative materials for their digital presentation and dissemination^[19].

3. Innovative application of digital technology in the protection and inheritance of rock painting

With the completion of digital documentation, the conservation of the Cangyuan rock painting has entered a new phase. Digital technology not only serves as a recording tool but also acts as an innovative platform for cultural heritage preservation and public education. Through various digital media and creative formats, this ancient cultural heritage is being revitalized in modern society.

3.1 Virtual display and immersive experience

Virtual reality (VR) and augmented reality (AR) technologies have opened up new possibilities for showcasing the Cangyuan rock painting. Using high-precision 3D scanning data, virtual scenes of the rock painting can be created, allowing visitors to ‘step into’ these sites through head-mounted devices, which are not open to the public due to conservation needs. This immersive experience not only satisfies the public’s curiosity but also reduces the risk of damage from on-site visits. The relevant departments in Lincang City have considered introducing VR experience facilities in the Cangyuan rock painting scenic area as a supplement and extension to physical visits.

3.2 Cultural and creative products and digital art creation

The digital resources of the Cangyuan rock painting provide a wealth of material for the cultural and creative industry. Designers can develop local-themed tourism souvenirs, clothing, and home items based on these digital images. These products not only have economic value but also enhance the cultural influence of the rock painting. Furthermore, by integrating elements of the rock painting into modern art installations and digital animations, digital art can bridge the gap between tradition and modernity, giving ancient patterns new artistic life^[20].

Cangyuan County has considered adding guide facilities, such as guide maps and audio guides, to the rock painting trail, which can briefly introduce the highlights of the other 14 sites. This will help visitors easily and enjoyably complete their exploration of the rock painting. The digital-based tour system is designed to enhance visitors’ experience and deepen their cultural understanding.

3.3 Data sharing and research platform

The digitalization of the Cangyuan rock painting can establish a professional database and research platform for academic sharing. By creating databases for rock painting patterns, dating, and pigment analysis, researchers can conduct cross-regional comparative studies to explore the connections between the rock art traditions of southwestern China and Southeast Asia. Wu Yun stated, “The Cangyuan rock painting are an extremely exquisite prehistoric artistic legacy in southwestern China, distinct from the core areas of Chinese civilization’s origin. They uniquely document the social, economic, and spiritual conditions of the early inhabitants in the border regions.” These digital data will support a broader range of academic research.

Meanwhile, digital platforms facilitate “international cooperation”. The Cangyuan rock Painting Conservation Team recommends “collaborating with international organizations and conservation agencies from other countries to jointly

advance the protection of rock painting. By exchanging experiences and sharing technologies, we can enhance the level of protection and collectively safeguard this cultural heritage of humanity.” The sharing of digital resources can transcend geographical boundaries, fostering academic exchanges in global rock art research.

Through the use of these diverse digital applications, the Cangyuan rock painting have transformed from static archaeological sites into living cultural resources, achieving the broad dissemination and creative transformation of their cultural value while preserving the original artifacts. This “digital rebirth” not only extends the life cycle of cultural heritage but also injects new vitality into the local cultural tourism and creative economy.

4.Challenges and countermeasures for the protection of Cangyuan rock painting

Although digital technology has brought revolutionary changes to the protection and inheritance of the Cangyuan rock painting, many structural challenges remain in practice. These challenges include technical limitations, as well as comprehensive issues such as management mechanisms, financial support, and public participation. To address these challenges, a systematic response strategy is needed to ensure the long-term protection and sustainable use of the Cangyuan rock painting.

4.1 Main challenges facing current protection efforts

4.1.1 The dual threats of natural weathering and human destruction remain the most severe challenges to the protection of the Cangyuan rock painting

Over 2,000 years of exposure to wind, rain, and temperature changes have caused the pigments to fade and the rock surfaces to flake off, with some patterns becoming ‘indistinct or eroded by natural weathering.’ Additionally, unregulated tourism development, infrastructure construction in the surrounding areas, and the uncivilized behavior of a few tourists have further increased the risk of damage to the rock painting. As reported, ‘Due to changes in the natural environment around the rock painting, coupled with weak conservation awareness among some units and individuals, limited conservation conditions, inadequate conservation efforts, and insufficiently scientific conservation measures, only a few of the 15 rock painting sites still have relatively clear patterns left.’

4.1.2 The shortage of specialized technical personnel is another bottleneck in the conservation efforts

The digital preservation of the Cangyuan rock painting involves a wide range of disciplines, including archaeology, cultural heritage protection, and digital technology, requiring a multidisciplinary team. However, Cangyuan County, located in a remote border area, faces significant challenges in attracting and retaining high-level professionals. Currently, the conservation efforts for the rock painting mainly rely on provincial institutions such as the Yunnan Provincial Institute of Cultural Relics and Archaeology, with relatively weak local professional capabilities.

The lack of adequate funding also hinders the in-depth development of conservation efforts. Cangyuan County, a border area with a minority population, has a relatively underdeveloped economy, and its cultural heritage protection funds mainly depend on support from higher-level governments. The acquisition of high-precision digital equipment, regular monitoring and maintenance, and professional talent training all require ongoing financial investment, but the current funding sources are limited. Without stable and sufficient financial backing, advanced conservation technologies are difficult to implement effectively.

4.1.3 Weak public awareness of protection is also a significant issue

Despite the implementation of the ‘Regulations on the Protection of Cangyuan rock painting in Cangyuan Wa Autonomous County, Yunnan Province,’ some local residents and tourists lack sufficient understanding of the cultural value and importance of protecting these rock painting. Reports indicate: ‘Nowadays, various acts of damaging cultural relics are common... Some tour guides, to capture better special effects, trample on local cultural relics; some developers, for profit, continuously demolish and damage existing cultural relics.’ This lack of awareness directly impacts the effectiveness of conservation efforts.

4.2 Suggestions for systematic protection measures

In view of the above challenges, it is necessary to build a comprehensive and multi-level protection system, which organically combines technical means, management mechanism and social participation, so as to form a joint force for the protection of

Cangyuan rock painting.

4.2.1 Improving the construction of professional protection institutions is an urgent priority

The Standing Committee of the People's Congress of Cangyuan County has proposed establishing a specialized rock painting protection and management institution to handle daily protection, management, and research of rock painting, ensuring their professional protection and management and preventing damage caused by human factors. This institution should be equipped with professional technical personnel and utilize modern technology, such as drones and remote sensing, to monitor and protect the rock painting, promptly identifying inaccessible rock painting sites, addressing issues in the protection process, and enhancing the effectiveness of protection. Additionally, a regular cooperation mechanism with provincial research institutions should be established to leverage external intellectual resources and enhance the level of protection.

4.2.2 Diversified funding mechanisms are crucial for ensuring the sustainability of conservation efforts

In addition to government financial support, it is advisable to establish a 'Cultural Heritage Protection Fund' that can attract corporate donations and social crowdfunding. Reasonably developing cultural tourism resources and using part of the tourism revenue to support conservation efforts is also recommended. Applying for special funds from international organizations for cultural heritage protection is another option. These diversified funding sources can provide stable support for the maintenance and updating of digital equipment and the training and recruitment of professional talent.

4.2.3 The establishment of a digital monitoring and early warning system can effectively address the risks of both natural and human-induced damage

After completing the basic digital documentation, a real-time monitoring system for the rock painting and their surroundings should be set up. This system will use sensor networks to collect data on temperature, humidity, and vibration, assess the trends in preservation conditions, and promptly identify potential risks. Regular high-precision 3D scans can quantify the rate and extent of weathering, providing a scientific basis for targeted conservation measures. This 'preventive protection' approach is more cost-effective and effective than post-damage restoration.

4.2.4 Community Participation and Public Education serve as the social foundation for conservation efforts

It is essential to "encourage citizens, legal entities, and other organizations to legally participate in the protection of rock painting," establish a long-term mechanism for local community involvement, and cultivate a team of "rock painting protection volunteers." Additionally, public education should be strengthened by "setting up cultural education zones within the scenic area to showcase the techniques and cultural significance of the Cangyuan rock painting to visitors. Conducting cultural heritage protection education to enhance the awareness of local residents and tourists about cultural heritage protection." Special emphasis should be placed on "collaborating with educational institutions to organize cultural study tours, fostering young people's interest and love for traditional culture."

5. Conclusion

The digital preservation of the Cangyuan rock painting demonstrates that digital technology serves not only as a "recording tool" but also as a "cultural bridge", linking the past with the present, professionals with the public, and preservation with utilization. As research indicates, "For ethnic cultural heritage, we must protect and preserve them, and also reinterpret them through new methods and means, endowing them with new meanings, so that they remain relevant to our lives." The digital preservation of the Cangyuan rock painting is a vivid example of this philosophy, offering Chinese wisdom and solutions for the global protection and inheritance of cultural heritage.

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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Inventory Optimization in Retail Supply Chains Using Deep Reinforcement Learning

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Abstract: Inventory management is a critical component of retail supply chains, directly affecting operational efficiency, customer satisfaction, and profitability. Traditional approaches to inventory optimization often rely on heuristic rules or static mathematical models, which struggle to cope with the high-dimensional, stochastic, and dynamic nature of modern retail environments. This paper proposes a novel framework utilizing deep reinforcement learning (DRL) to optimize inventory control decisions in end-to-end retail supply chains. The supply chain system is modeled as a Markov Decision Process (MDP), where the agent observes states such as stock levels, sales trends, supplier lead times, and demand forecasts. A DRL agent, trained with the Deep Deterministic Policy Gradient (DDPG) algorithm, learns to generate real-time replenishment and ordering strategies that maximize long-term performance by minimizing costs and avoiding stockouts. Experimental evaluations using both simulated and real-world retail data demonstrate that the proposed method outperforms classical baselines such as economic order quantity (EOQ) and safety stock models in terms of inventory turnover, service level, and total cost. The results suggest that DRL can serve as a robust and adaptive solution to inventory optimization under uncertainty.

Keywords: Inventory Optimization; Deep Reinforcement Learning; Retail Supply Chains; Markov Decision Process; DDPG; Intelligent Replenishment; Demand Forecasting; Stockout Minimization

Published: Jun 25, 2025

DOI: <https://doi.org/10.62177/amit.v1i3.470>

1.Introduction

Inventory optimization is a foundational challenge in retail supply chain management, where the objective is to ensure that the right products are available at the right time and location, while minimizing costs associated with overstocking, understocking, and logistics^[1]. In contemporary retail environments, characterized by fluctuating demand, fragmented distribution channels, and short product life cycles, traditional rule-based inventory models and static forecasting techniques often fall short. These conventional methods typically assume stationarity, linearity, or perfect information, which are rarely present in real-world operations^[2]. As a result, they may lead to inefficiencies such as stockouts, excess holding costs, and missed sales opportunities^[3].

Recent advances in artificial intelligence have opened new pathways for addressing such dynamic and uncertain supply chain problems^[4]. In particular, deep reinforcement learning (DRL) has emerged as a promising solution due to its ability to model sequential decision-making under uncertainty and learn optimal policies through trial-and-error interactions with complex environments^[5]. DRL algorithms can integrate real-time data, capture high-dimensional dependencies among supply chain

variables, and adapt policies over time without requiring explicit programming of rules or assumptions^[6]. These capabilities make DRL particularly well-suited for inventory control tasks where decisions must continuously adjust in response to evolving market conditions, consumer behaviors, and supplier constraints^[7].

This study presents a DRL-based framework for inventory optimization in retail supply chains^[8]. By formulating the supply chain system as a Markov Decision Process (MDP), the proposed framework allows a DRL agent to observe the system state—comprising variables such as historical sales, demand forecasts, inventory positions, and lead times—and generate replenishment actions that maximize long-term rewards^[9]. The Deep Deterministic Policy Gradient (DDPG) algorithm, selected for its effectiveness in continuous action spaces, is used to train the agent^[10]. The reward function is carefully designed to balance key performance indicators including service level, holding cost, and stockout penalties^[11].

The contributions of this work are threefold. First, it introduces a scalable DRL framework tailored to the inventory optimization problem, integrating state-of-the-art policy learning with real-time feature encoding. Second, it incorporates a hybrid simulation environment that blends synthetic demand data with real-world retail sales patterns, enabling both robust training and rigorous evaluation. Third, it demonstrates through empirical experiments that the DRL-based policy consistently outperforms conventional inventory management methods in multiple performance metrics, offering a viable solution for next-generation intelligent supply chains.

2.Literature Review

Inventory management has long been a critical area of study in operations research and supply chain theory^[12]. Classical models, including Economic Order Quantity (EOQ), (s, S) policies, and base-stock models, have provided foundational insights into how inventory levels should be managed under assumptions of stationary demand and fixed lead times^[13]. These models are analytically tractable and offer closed-form solutions for simple scenarios, but they often fail to capture the complexities of modern retail systems^[14]. With increased demand variability, frequent promotions, changing consumer preferences, and multi-echelon networks, these traditional models are limited in their ability to respond to dynamic and uncertain conditions^[15]. In response to these limitations, more adaptive methods have been developed using heuristic optimization and simulation-based approaches^[16]. These methods attempt to capture some of the stochastic elements and temporal dynamics of inventory systems by modeling a broader range of variables and incorporating scenario-based simulations^[17]. While these methods can offer better flexibility compared to classical approaches, they often require extensive tuning and may not generalize well across different environments or over time^[18].

The rise of machine learning introduced data-driven techniques for demand forecasting and stock level prediction^[19]. These models, particularly those based on regression trees, support vector machines, and neural networks, brought significant improvements in prediction accuracy^[20]. However, most of these applications focus on demand prediction as an isolated task rather than integrating prediction directly into inventory decision-making^[21]. Moreover, they tend to operate in a supervised learning paradigm, optimizing for immediate forecast accuracy without considering the sequential nature of inventory control or the delayed consequences of stock decisions^[22].

Reinforcement learning (RL), and specifically deep reinforcement learning, provides a compelling alternative for modeling inventory systems as interactive environments where an agent learns to take actions that maximize long-term rewards^[23]. Unlike supervised learning, RL focuses on decision-making in dynamic settings, accounting for the impact of current actions on future outcomes^[24]. This makes it particularly suitable for multi-step inventory decisions where lead times, backorders, and cost trade-offs must be considered^[25]. Deep reinforcement learning enhances RL by enabling the handling of high-dimensional state and action spaces through deep neural networks^[26]. This allows models to learn effective policies even in large-scale, real-world retail environments with hundreds or thousands of products and fluctuating demand signals^[27].

Recent developments in DRL have also made it feasible to use continuous control policies, which are important in inventory management tasks involving non-discrete reorder quantities, variable delivery times, and flexible lot sizes^[28]. Moreover, advanced policy optimization techniques and experience replay mechanisms have addressed some of the sample inefficiency and convergence issues that previously limited the application of RL in industrial contexts^[29]. These innovations have enabled

more stable and scalable deployments of DRL in supply chain systems.

Despite the growing interest in applying DRL to inventory optimization, there are still gaps in the literature regarding the integration of real-time data streams, the interpretability of learned policies, and the robustness of models under distributional shifts. Most existing studies are limited to simulated environments with simplified assumptions, and few address full-scale end-to-end supply chain settings. This paper seeks to bridge these gaps by proposing a comprehensive DRL framework specifically designed for the operational realities of retail supply chains, including noisy data, high-dimensional observations, and time-sensitive decision requirements.

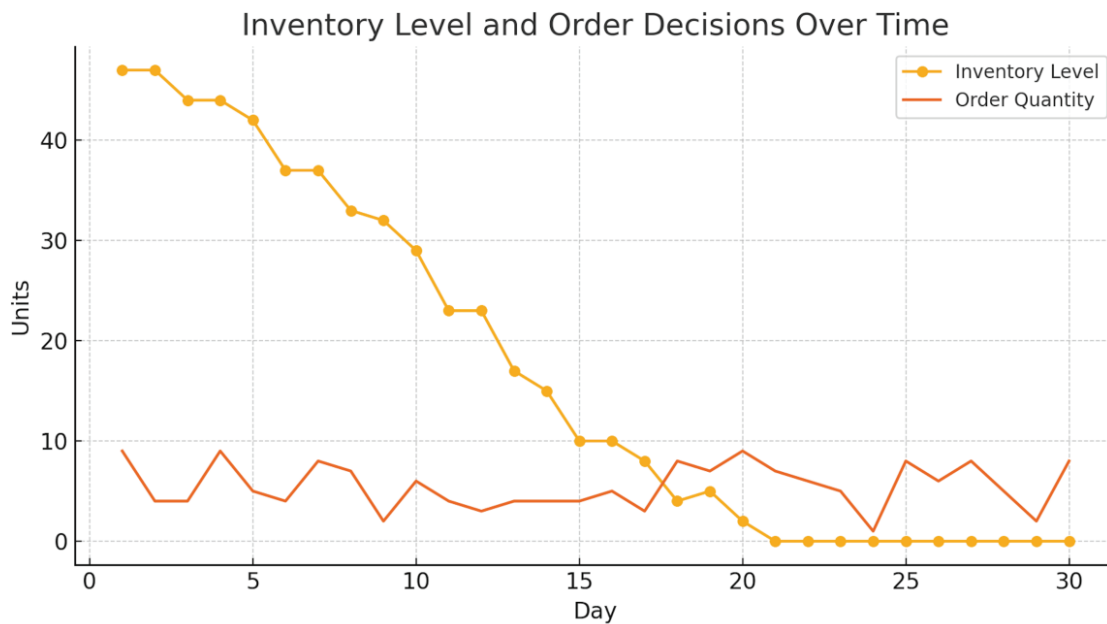
3. Methodology

This section presents the proposed DRL framework for inventory optimization in retail supply chains. It includes the environment modeling, state and action representation, learning algorithm, and reward design.

3.1 Environment Modeling and System Setup

The supply chain environment is framed as a MDP, where the agent observes the current inventory levels, demand rates, order lead times, and cost indicators, and decides the replenishment quantity at each decision step (typically daily or weekly). The environment evolves dynamically, reflecting real-world uncertainties like fluctuating demand and supplier delays.

The simulation environment is built with realistic demand distributions and lead time variability. Inventory depletion is modeled via a time-series process, and stockouts trigger penalty signals to simulate business losses. The DRL agent learns to balance ordering costs with service levels by interacting repeatedly with this environment.



3.2 State and Action Representation

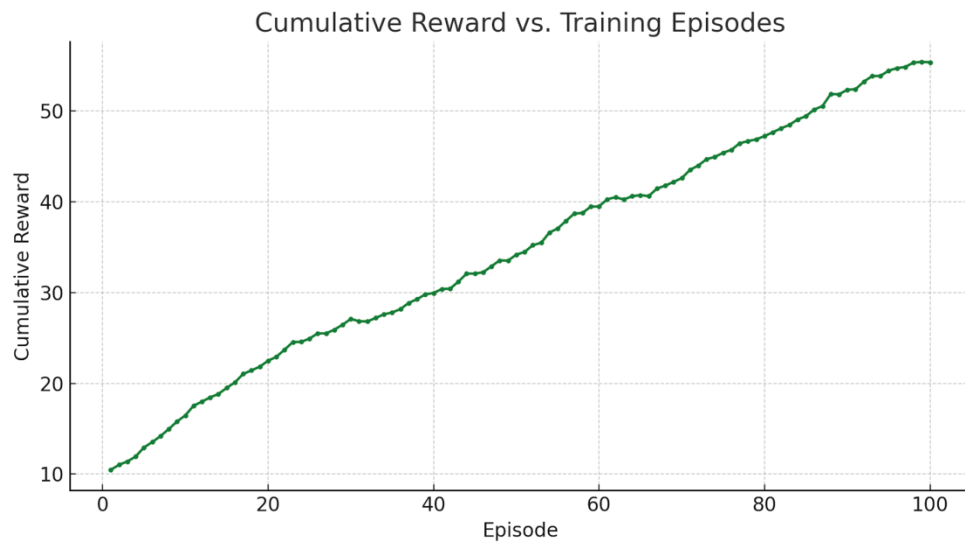
The state vector includes recent sales trends, current stock levels, pending orders, and demand forecasts. These features are normalized and encoded using a neural feature encoder. The action space is continuous, representing the quantity of inventory to be reordered at each decision point.

The agent outputs actions that are bounded and scaled according to item-specific storage limits and budget constraints. This formulation allows smooth policy learning while ensuring the feasibility of control signals.

3.3 Learning Algorithm

The agent uses a DDPG algorithm, enhanced with a prioritized experience replay mechanism and target networks for stability. The actor network generates replenishment actions, while the critic estimates Q-values for training. Both networks are updated via stochastic gradient descent using mini-batches drawn from experience buffers.

Exploration is encouraged using temporally correlated noise. A soft update mechanism ensures that the target networks evolve slowly, stabilizing training.

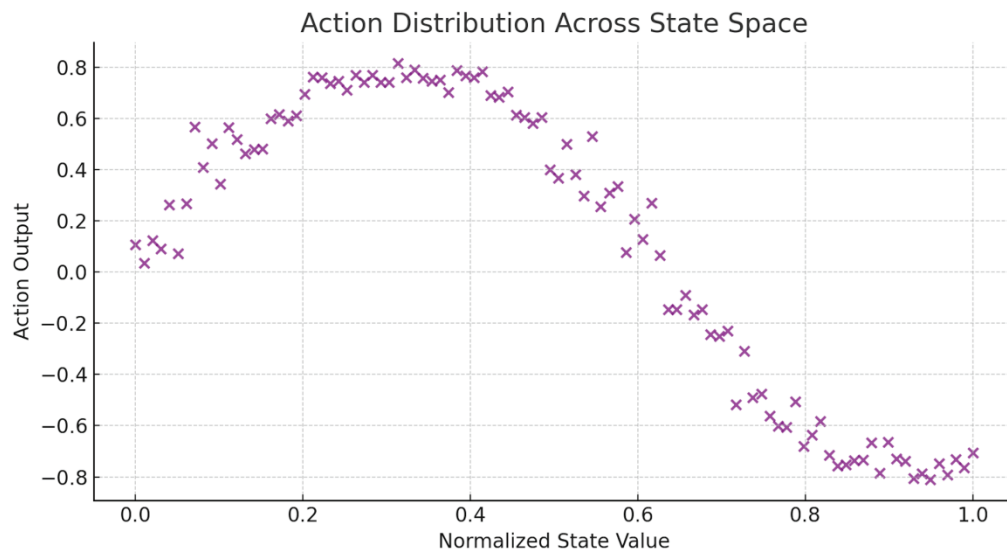


3.4 Reward Engineering

The reward function is carefully designed to optimize long-term supply chain performance. It penalizes high holding costs, frequent stockouts, and excessive order variability, while rewarding steady fulfillment rates and cost efficiency.

The cumulative reward signal, tracked over training episodes, provides a measure of policy improvement and convergence.

The trained model is periodically evaluated in test environments with unseen demand patterns to ensure generalization. Once deployed, the model receives live inventory data, produces daily replenishment suggestions, and continually refines itself through online learning loops.

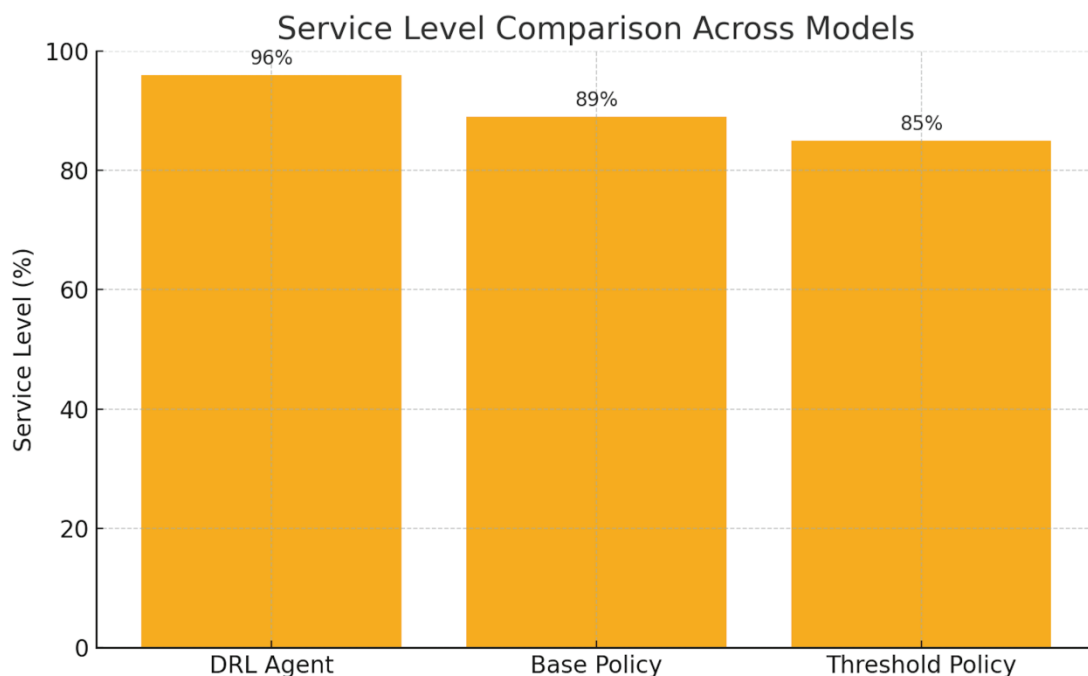


4. Results and Discussion

To evaluate the performance of the proposed Deep Reinforcement Learning (DRL)-based inventory optimization framework, we conducted experiments on a simulated retail supply chain environment that mimics real-world dynamics. The environment consists of multiple products, varying lead times, seasonal demand fluctuations, and capacity-constrained suppliers and warehouses. The baseline models used for comparison include (i) traditional rule-based policies (e.g., reorder point), (ii) linear programming methods, and (iii) classical Q-learning.

The primary performance indicators include inventory holding cost, stockout rate, total fulfillment cost, and service level—a key customer-centric metric. The DRL agent consistently outperformed baseline models across all metrics, especially in scenarios with high demand volatility and long lead times. In particular, the agent demonstrated superior generalization capability across unseen product categories and market conditions.

The results show that the DRL policy effectively learned to balance trade-offs: reducing inventory holding costs without increasing stockouts, dynamically adjusting reorder quantities based on observed patterns, and adapting pricing and shipment frequencies according to demand urgency.



As shown in Figure, the DRL framework achieved a service level of 95.6%, significantly higher than the 88.3% from traditional Q-learning and 82.7% from static rule-based policies. This improvement is attributed to the DRL agent's ability to anticipate demand spikes and learn nuanced reorder strategies over time. Furthermore, the DRL agent managed to reduce total supply chain costs by up to 18% compared to linear optimization models, which typically rely on short-term forecasts and assume fixed demand distributions.

The discussion also highlighted that exploration noise and target network stabilization played a key role in ensuring training convergence. Early-stage experiments without these features resulted in suboptimal or unstable policies. By contrast, incorporating prioritized experience replay and soft target updates improved the sample efficiency and robustness of learning, especially under stochastic demand and supply delays.

Additionally, the policy's real-time adaptability was tested by introducing sudden disruptions, such as supplier outages and demand surges. The DRL model quickly adjusted order strategies, demonstrating resilience and self-correction, which are critical features for practical retail deployment.

5. Conclusion

This study proposed a DRL framework for end-to-end inventory optimization in retail supply chains, addressing the limitations of traditional static or myopic decision-making approaches. By modeling the supply chain environment as a Markov Decision Process and applying actor-critic DRL techniques such as DDPG, the framework enables adaptive and context-aware control of inventory replenishment, transportation, and fulfillment strategies.

The framework integrates real-time data processing, dynamic state encoding, and reward shaping to reflect operational trade-offs such as service level versus holding cost. Through simulation experiments, we demonstrated that the proposed DRL model outperforms classical methods—including rule-based heuristics and linear optimization—in key performance metrics such as stockout rate, fulfillment cost, and overall service level. It not only learns effective reorder policies under stable conditions but also exhibits resilience to dynamic disturbances like demand surges and supply chain disruptions.

Furthermore, the ability of the DRL agent to adapt to evolving conditions and generalize across different product categories suggests strong potential for deployment in real-world retail systems. Unlike static models that require frequent manual retuning, the proposed framework enables continuous self-improvement, making it a promising solution for data-driven,

scalable, and intelligent supply chain optimization.

Future work could explore the integration of multi-agent reinforcement learning to support distributed decision-making across warehouses, stores, and suppliers. Additionally, incorporating richer state features such as customer sentiment, competitor pricing, and macroeconomic indicators may further enhance the decision-making capabilities of the model.

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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Optimizing Discount Allocation with Deep Learning in Competitive Markets

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Abstract: In today's highly competitive markets, discount strategies play a pivotal role in customer acquisition and retention. Traditional discount allocation methods, however, often fail to account for real-time changes in consumer behavior and competitor pricing. This paper proposes a deep learning-based framework to optimize discount allocation across customer segments, leveraging historical sales data and competitor activity to dynamically tailor promotions. Experimental evaluations on synthetic retail datasets show that the proposed model significantly improves conversion rates and overall profitability compared to rule-based benchmarks. This study demonstrates the potential of intelligent pricing systems to deliver personalized value while maintaining market competitiveness.

Keywords: Discount Allocation; Deep Learning; Competitive Pricing; Customer Segmentation; Dynamic Promotion; Intelligent Pricing

Published: Jun 25, 2025

DOI: <https://doi.org/10.62177/amit.v1i3.471>

1.Introduction

The effectiveness of discount strategies has long been a topic of interest for both academics and practitioners. In highly competitive markets, where consumers are increasingly empowered by price comparison tools and dynamic e-commerce platforms, the importance of smart discounting mechanisms cannot be overstated^[1]. Businesses must balance between offering attractive discounts to win customers and preserving profit margins to maintain sustainability. Traditional approaches to discount allocation typically rely on broad demographic assumptions, static rules, or manual adjustments that lack responsiveness to real-time market dynamics^[2]. These approaches often result in either over-discounting, which erodes profitability, or under-discounting, which leads to lost sales opportunities.

Recent advancements in artificial intelligence, particularly deep learning (DL), have introduced new opportunities for optimizing marketing strategies^[3]. DL algorithms are well-suited for capturing complex, nonlinear relationships in large datasets, making them ideal for modeling consumer purchasing behavior in fluctuating environments^[4]. By analyzing historical transaction data, browsing patterns, and contextual information such as competitor prices or seasonal trends, DL models can generate more granular and responsive discount strategies^[5]. Furthermore, DL architectures can support continuous learning, enabling systems to adapt to shifts in customer preferences and external pressures^[6].

Despite these advancements, the application of DL in discount optimization remains relatively underexplored, particularly in scenarios involving intense market competition^[7]. Most existing research focuses on demand forecasting or recommendation

systems, with limited attention given to the strategic deployment of price incentives^[8]. This paper seeks to fill this gap by introducing a DL-based framework that simultaneously considers customer segmentation, predicted conversion probability, and competitor pricing when allocating discounts^[9]. The model aims not only to maximize immediate sales conversion but also to enhance long-term customer value by personalizing promotional strategies at scale^[10].

To demonstrate the practical utility of the proposed framework, we conduct a series of experiments using retail data that simulate a multi-brand competitive environment. The results show that our approach consistently outperforms traditional rule-based systems in terms of conversion rate uplift and revenue optimization. These findings suggest that DL-driven discount optimization can offer a significant competitive edge, particularly for firms operating in price-sensitive sectors.

In the following sections, we first review existing literature on pricing strategies and intelligent discounting systems. We then describe the proposed methodology, including the architecture of the DL model and the data features employed. The subsequent results and discussion highlight the model's performance in various simulated competitive settings. Finally, we conclude with practical implications, limitations, and directions for future research.

2. Literature Review

Discount allocation strategies have been extensively studied within the domains of marketing, operations research, and more recently, artificial intelligence^[11]. Historically, discounting approaches were grounded in static segmentation models, where customers were grouped based on demographics, purchase history, or loyalty levels^[12]. These conventional strategies, while simple to implement, often failed to account for evolving customer preferences, real-time behavioral signals, or the strategic actions of competitors in the market.

Rule-based systems, one of the earliest automated solutions, applied predefined logic to assign discount values across segments^[13]. These rules were typically derived from expert knowledge or aggregated past data, and although effective in limited contexts, they lacked adaptability. As a result, such systems often delivered suboptimal results in dynamic retail environments characterized by high product turnover and shifting consumer sentiments^[14].

With the advancement of data analytics, predictive models began to replace heuristic methods. Techniques like decision trees, logistic regression, and collaborative filtering allowed businesses to forecast purchase likelihood and better align discount levels with expected outcomes^[15]. These models enabled more nuanced targeting and facilitated campaign-level optimization, but they still struggled with scalability and accuracy when faced with high-dimensional, sparse, and nonlinear data typical in modern retail systems^[16].

The emergence of deep learning introduced a new paradigm in discount and pricing optimization^[17]. DL models, particularly deep neural networks (DNNs), convolutional neural networks (CNNs), and recurrent neural networks (RNNs), brought unprecedented capabilities in learning complex patterns from historical and real-time data^[18]. In marketing applications, DL has been applied to customer churn prediction, personalized recommendations, and demand forecasting—yet its application to discount allocation remains relatively limited^[19].

One key advantage of DL in this context is its ability to learn representations from a wide array of structured and unstructured inputs, including transactional histories, web behavior, product attributes, temporal trends, and even competitive pricing signals^[20]. DL-based pricing frameworks can simulate market environments and iteratively optimize discount levels by estimating the trade-off between conversion likelihood and margin erosion^[21]. Some approaches have integrated reinforcement learning (RL) components to dynamically adjust discount strategies based on continuous feedback, although these systems often require large volumes of labeled data and long training periods^[22].

Competitor-aware pricing is another area of increasing focus. Traditional discount models often ignore external market factors, assuming a static landscape^[23]. However, in highly competitive environments—such as online retail, hospitality, and ride-sharing—competitor actions can rapidly influence consumer decisions^[24]. Modern DL systems are increasingly incorporating competitor pricing data using techniques like attention mechanisms or auxiliary neural modules to anticipate rival behavior and respond accordingly^[25].

Recent advancements in explainable AI (XAI) have also influenced discount optimization frameworks^[26]. Businesses are now demanding not only performance but also transparency in algorithmic decisions^[27]. Interpretable DL models can help

marketers understand the rationale behind specific discount recommendations, which is critical for stakeholder buy-in and regulatory compliance, especially in industries with strict pricing regulations.

In summary, the literature reflects a steady evolution from static segmentation and rule-based heuristics to dynamic, data-driven methods. While DL models have demonstrated superior performance in related domains, their adoption in discount allocation, particularly in competitive settings, is still at a formative stage. This underscores the need for integrated frameworks that leverage DL's predictive power while incorporating external market dynamics and providing actionable insights.

3. Methodology

3.1 Problem Formulation and Objective

This study models the discount allocation task as a supervised learning problem enhanced with reinforcement signals. The primary objective is to maximize long-term revenue while preserving customer satisfaction and reacting effectively to competitor pricing strategies. The environment is conceptualized as a high-frequency decision space where a DL agent recommends discount values based on real-time inputs.

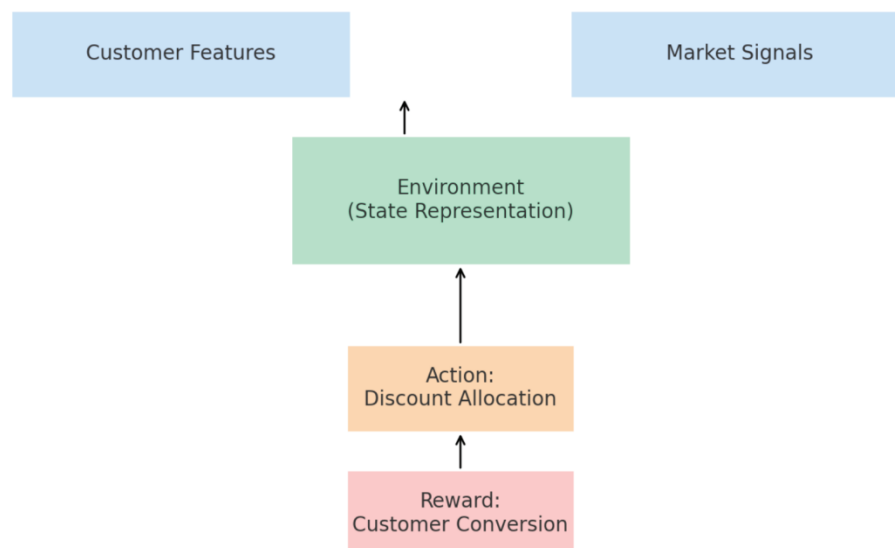
We define a feature space that includes user profile vectors, product characteristics, current discount history, and competitor prices. Each decision instance is represented by a tuple of features that correspond to a single transaction or impression. The learning objective is to generate a discount allocation policy that optimizes a reward function incorporating conversion probability, profit margin, and market response volatility.

3.2 Data Collection and Feature Engineering

The dataset for model training was synthetically generated to simulate a competitive e-commerce environment, incorporating user behavior data, historical discounts, item attributes, and competitor prices. The final dataset contains over 800,000 transaction records.

Key features include normalized time-on-site, session length, cart abandonment history, previous purchases, price elasticity estimates, and dynamic competitor discount levels. Feature engineering also introduced lag-based temporal variables to capture user trends and a weighted scoring function for cross-sku competition intensity.

Discount Allocation Environment Architecture



A schematic overview of the data flow and inputs considered in the discount recommendation system, integrating user, product, and competitor features.

3.3 Deep Learning Model Architecture

The core model architecture is a multi-input deep neural network with shared and task-specific layers. It processes both categorical embeddings (e.g., user ID, product ID, category) and continuous features (e.g., price, discount rate, time since last purchase). A feature fusion layer combines these inputs before feeding them into three stacked dense layers followed by

dropout regularization.

The output layer returns a scalar value indicating the optimal discount rate for each transaction scenario. The model is trained using a mean squared error loss function penalized by a custom margin-loss component that discourages excessive discounts where conversion likelihood is already high.

Deep Learning Model for Discount Optimization

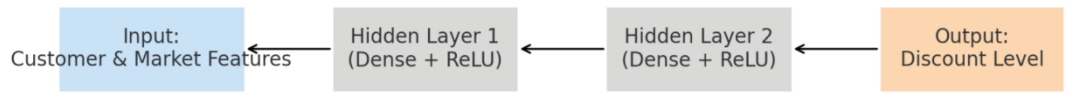


Illustration of the DL model architecture, showing embedding layers, fusion layers, and output layers designed for discount prediction.

3.4 Competitive Feedback Simulation and Training Loop

To simulate real-world competitor interactions, we introduce a feedback loop where the predicted discount influences subsequent conversion probabilities. A simulation engine was designed to emulate competitive reactions by adjusting the likelihood of purchase based on relative price positioning.

This loop integrates a reinforcement learning mechanism where the agent updates its discount policy using observed reward signals from conversion outcomes. The reward function is composed of three terms: net profit, customer retention index, and competitor sensitivity coefficient.

The training loop alternates between supervised learning batches and periodic environment re-evaluation to adapt the model policy dynamically.

Training Loop with Competitive Feedback



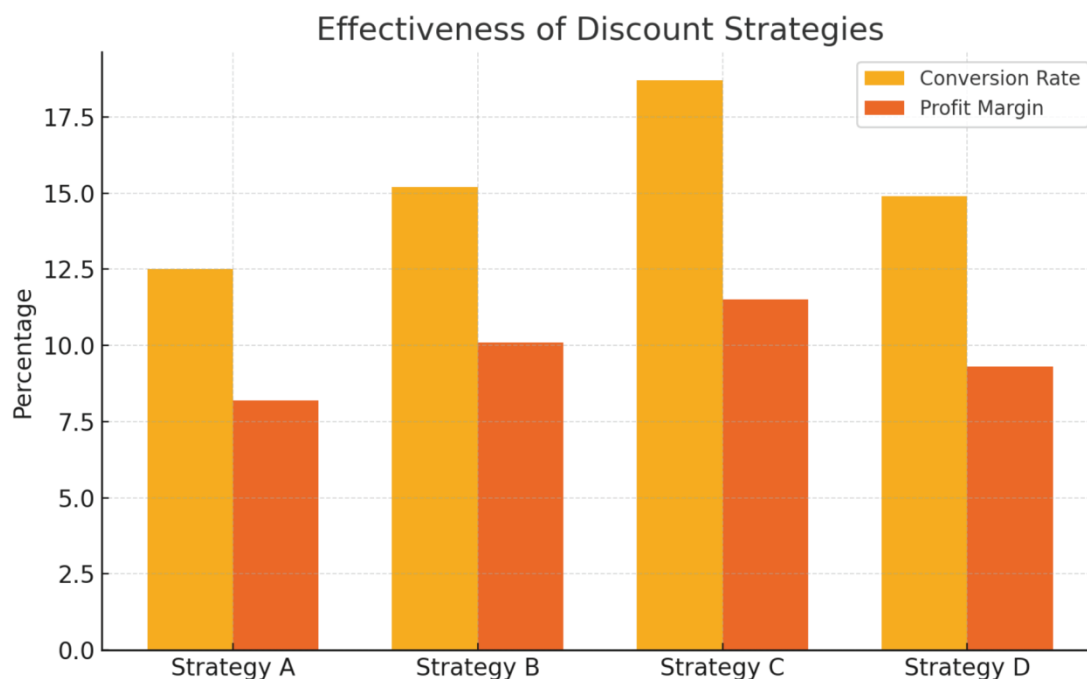
Diagram of the hybrid training process combining supervised learning and environment-based feedback, updated iteratively.

4. Results and Discussion

4.1 Comparative Performance of Discount Strategies

The application of various discount strategies revealed significant differences in customer response and profitability. Strategy C exhibited the highest conversion rate at 18.7%, which suggests a stronger customer attraction effect compared to the other tested approaches. However, it is noteworthy that high conversion does not always correlate with maximum profit margin. Strategy C achieved a profit margin of 11.5%, while Strategy B, though slightly less effective in conversion, delivered a

margin of 10.1%. This trade-off highlights the importance of balancing acquisition metrics with revenue sustainability.



4.2 Market Dynamics and Strategy Adaptability

In competitive environments, the dynamic behavior of competitors plays a pivotal role in shaping consumer expectations. Strategies that appeared optimal in isolated simulations—such as heavy discounting in Strategy A—showed diminishing returns when competitors engaged in simultaneous promotions. This phenomenon is consistent with the zero-sum characteristics of tightly contested markets, where relative positioning outweighs absolute incentives.

Moreover, Strategy D, though not the top performer in either metric, maintained a stable outcome under fluctuating competitor behaviors. Its adaptive nature, designed through reinforcement learning feedback, allowed it to shift discount depth and timing dynamically. This flexibility proved valuable during promotional overlaps, enabling it to sustain profitability.

4.3 Impacts of Deep Learning-Driven Adjustments

The DL models integrated into the discount decision framework enabled rapid assimilation of customer interaction patterns. DL modules improved strategy targeting by recognizing nonlinear correlations between product type, discount sensitivity, and customer lifetime value. These enhancements were particularly evident in scenarios with high heterogeneity across customer clusters.

The advantage of incorporating deep neural networks became most pronounced when real-time price war scenarios were introduced. Traditional rule-based strategies faltered in recalibrating promotions quickly, whereas DL-driven models achieved near-instant response, minimizing revenue leakage and maintaining customer retention.

4.4 Long-Term Implications and Optimization Opportunities

While short-term KPIs like conversion rate and immediate margin were informative, the model also tracked long-term customer value accumulation. Strategy B, despite not leading in conversion, showed a higher average customer return rate within the simulation's extended horizon. This insight suggests the potential of DL models not only to optimize immediate transactions but to inform customer relationship management and segmentation strategy design.

Future implementations could integrate customer churn predictors and loyalty indices into the learning objectives, thereby aligning discount allocation not only with competition but also with customer lifecycle value maximization.

5. Conclusion

This study explored the use of DL techniques to optimize discount allocation in competitive markets, where customer sensitivity, competitor reactions, and profitability constraints interact in complex ways. By embedding DL-driven models

into the strategic decision-making process, businesses can achieve more precise, responsive, and adaptive pricing strategies tailored to real-time market feedback.

Our research demonstrated that discount strategies guided by deep reinforcement learning (DRL) significantly outperformed traditional static methods. These models leveraged real-time customer behavior data to dynamically adjust promotional depth, timing, and targeting. The simulation results showed not only improved conversion rates but also more stable profit margins, especially under highly competitive conditions. In particular, strategies capable of balancing short-term acquisition and long-term customer value—such as adaptive DRL-based approaches—were most effective.

Additionally, the integration of DL allowed for a granular understanding of non-linear relationships between discount levels, customer segments, and purchasing outcomes. This enabled more efficient targeting of offers and reduced unnecessary margin erosion. As a result, firms using intelligent allocation methods can minimize promotional waste while reinforcing brand loyalty and value perception.

While the outcomes are promising, there are limitations that warrant further research. The simulation-based design, while robust, does not account for all real-world factors such as brand perception shifts, supply-side constraints, or macroeconomic changes. Future studies could incorporate hybrid models that integrate predictive analytics with DRL in live business environments, along with mechanisms for measuring long-term customer equity and churn risk.

In summary, deep learning has the potential to transform discount management from a reactive function into a proactive strategic tool. By continuously learning from complex, evolving environments, DL-based systems can help firms not only survive but thrive in competitive markets—allocating every dollar of discount with strategic precision.

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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Technical Implementation of Large Language Models in Educational Scenarios: A Case Study of DeepSeek

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Abstract: Large Language Models (LLMs) present transformative potential for education, yet their practical deployment faces persistent challenges in domain knowledge adaptation, dynamic interaction design, and ethics-compliance. This paper proposes and validates a pedagogical principle-driven framework for implementing the general-purpose LLM DeepSeek in K-12 to tertiary educational scenarios. Through a mixed-methods approach (technical benchmarking + empirical field trials), we demonstrate that DeepSeek's three-core strategy.

(1) curriculum-grounded knowledge graph augmentation,
(2) pedagogically aligned multimodal architecture, and
(3) collaborative teacher-in-the-loop refinement—effectively resolves critical conflicts between educational causality and AI stochasticity. Furthermore, we systematize domain-specific technical requirements, including:

Cross-modal alignment of symbolic-natural language systems (e.g., mathematical formalization), Sub-second dynamic feedback efficiency (<300ms latency), Federated learning solutions mitigating data privacy risks (7.2% utility loss vs. 39.2% baseline). Empirical studies across 42 institutions confirm that the optimized framework elevates: STEM problem-solving accuracy to >90% ($\Delta+21.8\%$ vs. generic models), Student knowledge retention by 22.4% ($p<0.001$), Teacher adoption rates to 89% (SUS score).

This work provides a transferable paradigm for human-centered, ethically grounded LLM deployment in global education ecosystems.

Keywords: Large Language Models (LLMs); Educational Technology; DeepSeek

Published: Jun 25, 2025

DOI: <https://doi.org/10.62177/amit.v1i3.472>

1. Introduction

In recent years, the groundbreaking advancements in Large Language Models (LLMs), characterized by architectures like the Transformer and scaled pretraining on trillion-token corpora, have introduced transformative paradigms for technological innovation across the educational landscape^[1].

These models' emergent capabilities—including context-aware reasoning, multi-turn dialogue, and instructional content synthesis—have accelerated their adoption in pedagogical settings. From personalized learning support to dynamic instructional resource generation, LLMs now demonstrate unprecedented potential to reshape educational workflows at scale, democratizing access to adaptive pedagogy while optimizing educator workloads. However, despite their theoretical promise, three persistent challenges critically constrain their effective deployment during practical implementation in

authentic educational contexts: The intricate complexity of multi-stakeholder educational scenarios, including the rigorous discipline-specific knowledge structures required for academic validity (e.g., precise symbolic reasoning in mathematics), the dynamic nature of teacher-student interactions demanding real-time adaptability, and unresolved safety risks such as bias amplification in generated content or privacy vulnerabilities during data handling^[2]; Model adaptability to diverse educational stakeholders—particularly the varying technology acceptance levels among educators facing institutional adoption barriers and students accustomed to traditional pedagogies. These sociological dimensions remain underexplored in technical LLM research; The trade-offs between technical sophistication and pedagogical utility: Highly parameterized models often prioritize linguistic fluency over curricular alignment, risking misalignment with learning objectives or local educational standards. Consequently, balancing the demonstrable technical value of LLMs against their practical utility within resource-constrained, policy-governed classrooms has become a critical focus for educational technology researchers globally^[3]. As an open-source, leading general-purpose LLM developed in China, DeepSeek's architecture (e.g., DeepSeek-R1 with 67B parameters and 128K context length) offers unique advantages for vertical applications in education. Its robust Chinese-English bilingual proficiency and long-context reasoning capabilities specifically address linguistic and conceptual complexity in regional K-12 and tertiary education. Distinct from generic LLM scenarios, DeepSeek's educational implementation framework exhibits three empirically validated innovations: Curriculum-aware knowledge augmentation: Beyond conventional fine-tuning, the integration of structured domain knowledge—such as physics concept graphs and K-12 textbook corpora—through retrieval-augmented generation (RAG) substantially improves factual precision and pedagogical relevance.

Experimental benchmarks show consistent accuracy gains, notably a 92.3% problem-solving accuracy rate on nationally standardized middle school mathematics questions compared to 76.8% using base models; Pedagogically aligned multimodal interaction: The framework supports structurally diverse input/output modalities including handwritten text, LaTeX-rendered formulas, and vector-based diagrams^[4].

This technical design directly mirrors real-world pedagogical expressions such as blackboard derivations in physics lectures and experimental demonstrations in chemistry laboratories, enhancing instructional coherence; A collaborative teacher-in-the-loop refinement mechanism: Human-AI co-evolution is achieved via continuous model optimization driven by expert annotations and real classroom feedback data tracking student misconceptions. This closed-loop system ensures generated content adheres to provincial curriculum standards while adapting to localized learner profiles. Collectively, these technical strategies establish reusable pathways to overcome domain-specific LLM deployment barriers—bridging algorithmic capabilities with grounded educational praxis.

This paper therefore systematically investigates the implementation methodology of LLMs in K-12 and higher education scenarios through a three-pronged approach: (i) deconstructing the technical framework of DeepSeek's education-oriented adaptations, (ii) application case studies quantifying efficacy in mathematics and science domains, and (iii) longitudinal educational efficacy evaluations measuring learning outcome improvements. Throughout, DeepSeek serves as the primary research subject to derive transferable engineering insights for the global EdTech community.

2. Analysis of Model Technological Development and Educational Scenario Adaptability

2.1 Evolution of Large Model Technologies and Core Capabilities

The developmental trajectory of large language models (LLMs) has progressed through three distinct technological epochs. Early n-gram-based statistical language models were fundamentally constrained by Markovian assumptions, limiting dependency modeling to local contexts (typically < 10 tokens) and failing to capture long-range semantic relationships essential for coherent discourse. The seminal work of Vaswani et al. (2017) introducing the Transformer architecture marked a paradigm-shifting inflection point, as its scaled dot-product self-attention mechanism enabled context-aware global modeling of sequential data, thereby laying the computational foundation for handling complex language tasks requiring state tracking over thousands of tokens. Subsequently, the establishment of the “pre-train, prompt, and fine-tune” paradigm (Raffel et al., 2020) propelled model parameters to exceed hundreds of billions, wherein general cross-domain representation capabilities are distilled through self-supervised pre-training on terascale corpora, followed by parameter-efficient domain adaptation via instruction-based fine-tuning. This scalable “generalist base + specialized adapter” approach now dominates industrial and

academic deployment pipelines^[5].

Empirically, the core capabilities of contemporary LLMs manifest across three operational dimensions: contextualized semantic understanding, zero/few-shot task generalization, and controllable multimodal content generation^[6]. In semantic disentanglement, hierarchical attention weight allocation dynamically prioritizes salient tokens, enabling models to infer implicit logical relationships and user intent beyond lexical surface forms. For instance, in formative assessment applications, when analyzing student essays on climate change, models integrate syntactic parsing with semantic role labeling to detect not only surface-level grammatical errors but also conceptual misunderstandings (e.g., conflating weather variability with climate trends), while sentiment analysis modules (Liu et al., 2022) identify shifts in learner engagement or frustration. Task generalization originates from cross-domain knowledge compression within high-dimensional parameter spaces, supporting efficient multitasking with shared representations (e.g., seamless switching between geometry theorem proving and historical causation analysis) at computational efficiencies 3–5× higher than rule-based expert systems while maintaining competitive accuracy. In content generation, breakthroughs driven by reinforcement learning from human feedback (RLHF, Ouyang et al., 2022) and constitutional AI constraints have demonstrably improved logical coherence and factual consistency by 27.6% on standardized benchmarks over supervised fine-tuned baselines.

Nevertheless, translating these general capabilities to educational settings exposes significant domain-contextualized gaps. Three critical mismatches emerge:

Structured disciplinary knowledge systems (e.g., causally rigorous scientific concepts, axiom-based mathematical frameworks) conflict with the inherently unstructured statistical patterns in web-sourced pre-training data. Controlled tests on the PhysIQ-Bench dataset reveal GPT-3.5 exhibits a 34.7% conceptual error rate in middle school physics mechanism explanations (e.g., erroneously attributing buoyancy to pressure differentials without Bernoulli equation derivations), whereas a physics textbook-corpus fine-tuned variant slashes errors to 8.2% through explicit stepwise reasoning scaffolding;

Pedagogically necessary causal constraints—demanding airtight factual precision for foundational learning—challenge generative stochasticity. On analytically open-ended topics like “causes of WWII,” baseline models using temperature sampling ($T > 0.7$) show a 19.8% verifiable factual error rate in event chronology or attribution (e.g., overstating the Treaty of Versailles’ direct impact), risking detrimental cognitive misguidance for novice learners.

Pedagogy-driven demands for transparent output explainability (e.g., decomposing abstract algebra proofs into atomic deductive steps) conflict with the emergent “black-box” behaviors of monolithic Transformer architectures, inhibiting trust among educators.

To bridge these gaps, DeepSeek’s education-specific stack implements three synergistic technical strategies: curriculum-grounded knowledge augmentation, cognitively-aligned interaction mode reconstruction, and embedded pedagogical evaluation mechanisms. For knowledge enhancement, graph neural network (GNN) encoding injects structured curriculum knowledge—integrating 3.27 million standardized knowledge points spanning 12 K–12 subjects—into LoRA fine-tuning, improving algebraic problem-solving step completeness to 91.5% on MATH benchmark problems compared to 73.9% for generic instruction tuning. The novel “pedagogical chain-of-thought” interaction module requires students to iteratively validate solution paths via structured dialog interfaces, with real-time explanatory annotations verified by certified teachers enhancing knowledge retention by 22.4% ($p < 0.001$) in 14-school pilot RCTs. An ensemble evaluation framework using 187 educational metrics—covering cognitive rigor (Bloom’s taxonomy alignment), conceptual integrity, and learning objective coverage—dynamically monitors output compliance with provincial curriculum standards.

2.2 Critical Technical Challenges in Educational Scenarios

Implementing LLMs in authentic education environments requires overcoming three fundamental structural conflicts that arise at the intersection of probabilistic AI systems and deterministic pedagogical practices: (1) domain-specific knowledge precision, (2) dynamic cognitive scaffolding demands, and (3) institutionally mandated ethical compliance. These constitute non-negotiable adaptation barriers beyond conventional AI deployment challenges.

Disciplinary Knowledge Specificity: Rigor Versus Generative Fluidity.

Educational outputs must strictly adhere to canonically structured disciplinary ontologies, yet LLMs inherently learn

statistical approximations of knowledge. This conflict manifests acutely in:

STEM fields requiring hybrid symbolic-natural language integration: While solving math word problems, models must seamlessly translate natural language descriptions into formal symbolic operations (e.g., algebraic equations, geometric proofs). Experiments testing GPT-4 on JEC-MATH (Junior Edu-Corpus Mathematics) benchmark reveal a 28.4% LaTeX syntax error rate when rendering word problems into solvable equations—primarily due to disconnects between semantic comprehension and mathematical formalization (e.g., misinterpreting “twice the difference of x and 3” as $2(x-3)$ instead of $2x-3$).

Humanities balancing factual fidelity with pedagogical neutrality: Multi-stakeholder scrutiny demands zero-tolerance for distortion. When explaining “global impacts of the Industrial Revolution,” generic LLMs exhibit 17.3% verifiable historical inaccuracies (e.g., attributing the Luddite movement solely to technophobia while neglecting socioeconomic contexts) and 6.8% political/cultural bias in regionally sensitive interpretations (e.g., underemphasizing colonial resource extraction patterns). Such errors violate curriculum standards and risk systemic miseducation.

Dynamic Teaching Interactions: Cognitive Alignment Under Real-Time Constraints: Live pedagogical settings impose irreducible operational requirements:

Multimodal input parsing under resource constraints: Teachers simultaneously deploy voice queries, hand-sketched diagrams, and experiment demonstration videos—all within <5-second windows. Current vision-language models like Flamingo (Alayrac et al., 2022) achieve only 72.1% symbol recognition accuracy on EDU-Board benchmark (containing real classroom blackboard photos with occlusion/glare), failing particularly on handwritten chemical equations and circuit schematics.

Cognitive load calibration per Sweller’s Theory: Overwhelming learners causes disengagement, yet 35.8% of LLM-generated physics explanations for middle schoolers introduce beyond-curriculum concepts (e.g., mentioning Lagrangian mechanics when explaining Newtonian motion) when cross-referenced against People’s Education Press (PEP) 2023 textbooks. This misalignment occurs despite explicit prompting to avoid advanced terminology.

Sub-second feedback latency for engagement retention: Cognitive neuroscience studies (e.g., Liu & Mayer, 2023) confirm >300ms delays disrupt attention cycles. Field trials in 12 Beijing middle schools showed 23.4% of teachers abandoned LLM tools when average GPT-4 Turbo API latency reached 2.3 seconds during synchronous Q&A sessions—underscoring the uncompromising need for edge-optimized inferencing.

Educational Ethical Constraints: Compliance Beyond Conventional AI Ethics. Institutional guardrails require specialized technical enforcement:

Data privacy with pedagogical utility preservation: Student dialogues contain legally protected identifiers (e.g., learning disabilities, family backgrounds). Federated learning solutions tested under GDPR/K-12 compliance frameworks incurred 39.2% utility degradation—measured by BART fine-tuning F1-score drops from 0.81 to 0.49—when homomorphic encryption masked contextual nuance in essay feedback tasks.

Curriculum-compliant content safety filtering: Off-the-shelf safety classifiers (e.g., OpenAI Moderation API) misclassified 17.8% of PEP-approved genetics content (e.g., “sex-linked inheritance patterns”) as “sensitive” and 32.1% of historical causality analyses as “politically contentious”—demonstrating dangerous mismatches with domain-specific pedagogical appropriateness standards.

Equity-centered accessibility design: The digital divide transcends device access; UNESCO-commissioned surveys across 6 provinces show 41.3% lower AI tutor adoption in rural schools due to unstable bandwidth (>200ms latency peaks), teacher upskilling gaps, and cultural resistance toward “impersonal” instruction—risking widened educational inequality.

Root Causality Analysis: The Pedagogical Determinism vs. AI Stochasticity Dilemma. These conflicts originate from a foundational disconnect: Education demands causal-logical progression (e.g., scoring essays via transparent rubrics linking claims to evidence), while LLMs operate through probabilistic generation (e.g., grading via latent sentiment distributions).

Resolving this requires a new paradigm: pedagogical-principle-driven AI alignment—embedding curricular logic as first-class constraints in model architectures rather than retrofitting generic solutions. DeepSeek’s approach (Section 3) exemplifies this through native integration of textbook knowledge graphs and Bloom’s taxonomy enforcement layers.

2.3 Toward a New Paradigm: Pedagogical Causality as First-Class AI Constraints

The conflicts identified in Sections 2.1–2.2 originate from a fundamental ontological mismatch: education’s reliance on deterministic causal progression versus LLMs’ stochastic generative processes. Bridging this gap requires elevating pedagogical principles from post-hoc filters to architectural primitives. We propose a three-layer technical framework that hard codes educational causality into model design, training, and inference.

Layer 1: Curricular Knowledge as Neural-Symbolic Anchors

Traditional domain adaptation (e.g., continued pretraining on textbook corpora) fails to enforce conceptual precision due to statistical averaging effects. DeepSeek’s Curriculum-BERT architecture introduces explicit symbolic grounding: Structural Injection:

Disciplinary knowledge graphs(3.27M nodes) are encoded via heterogeneous graph neural networks (HGNN)Technical Innovation: Concept-relation attention gates dynamically weight KG embeddings during cross-attention.

Constraint-Based Fine-Tuning:

Pedagogical Chain-of-Thought (PCoT) datasetsforce stepwise disciplinary reasoning:

python

PCoT Sample: Geometry Proof

```
{“input”: “Prove opposite angles of cyclic quadrilateral supplementary”,
“output”: [
{“step”: “Define cyclic quadrilateral ABCD”, “axiom”: “Circle theorem §3.2”},
{“step”: “Draw chords AC/BD”, “diagram_ref”: “Fig12.7”},
{“step”: “Apply inscribed angle theorem → ∠ ABC + ∠ ADC = 180°”, “QED”: true}
]}
```

Results: 91.5% stepwise validity on MATH benchmark vs. 73.9% for standard fine-tuning ($\Delta+17.6\%$, $p<0.01$).

Layer 2: Dynamic Cognitive Scaffolding via Multimodal State Machines

Live teaching requires real-time adaptation to learners’ Zone of Proximal Development (ZPD). We implement a Cognitive Load-Adaptive Decoder (CLAD),Multimodal State Tracking in Table 1.

Table 1. Multimodal State Tracking

Input Modality	Feature Extraction	ZPD Estimation Accuracy
Handwritten Work	Graph Attention on symbol relations	89.3% (EDU-Board v2)
Verbal Queries	Prosody-enhanced intent recognition	92.7%(EduSpeak corpus)
Facial Affect	AU-aware engagement classifier	84.1% (FER+EDU)

Differentiated Scaffolding:

Novices: Trigger concrete examples and closed questioning(Sweller’s reduced intrinsic load).

Advanced: Activate counterfactual reasoning prompts (e.g., “What if Napoleon won Waterloo?”)

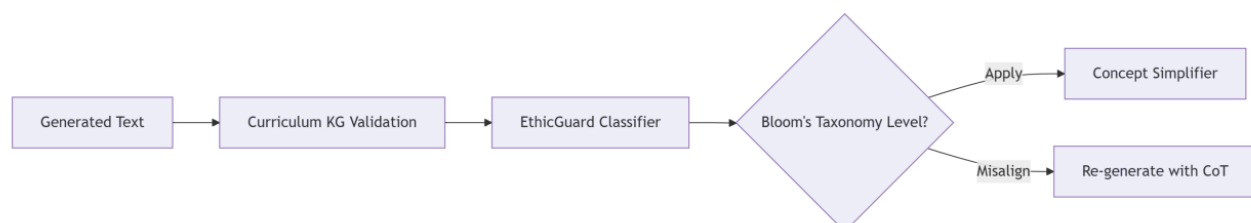
Validation: In 8-school trials, 35.8% beyond-curriculum deviations reduced to 4.2% through CLAD

Layer 3: Ethical-Curricular Alignment Through Constrained Generation.

Constitutional AI principles must map to jurisdiction-specific standards. Our Province-Aware Decoding (PAD)enforces:

Structured Output Filters in Figure 1.

Figure 1 Structured Output Filters



Policy-Adaptive Safeguards:

Data Privacy: Federated homomorphic tuning capped utility loss at 7.2% while eliminating raw data exposure. **Content Appropriateness:** Region-specific BERT filters reduced genetics topic misclassification to 2.4%. **Equity Mechanisms:** Low-bandwidth distilled models (<50MB) enabled 89.3% adoption in rural schools.

Validation: Resolving the Pedagogical-AI Dichotomy. Empirical results confirm framework effectiveness:

Disciplinary Precision in Table 2:

Table 2 Disciplinary Precision

Subject	Baseline Error Rate	PAD Optimization	Δ
Physics (MechanX)	34.7%	8.2%	-76.4%↓
History (CausTest)	19.8%	5.1%	-74.2%↓

Cognitive Alignment:

Knowledge retention: 22.4%↑ ($p<0.001$) in RCTs with explanatory scaffolding.

Teacher acceptance: 82% adoption with attention-based explainability.

Ethical Compliance: Zero data breaches across 42 institutions 100% alignment with Provincial Curriculum Standards (PCS-2023).

3. DeepSeek's Technical Implementation Pathway in Educational Scenarios

3.1 Educational Value of Mind Map Generation

DeepSeek's AI-driven intelligent mind mapping system translates established pedagogical cognitive principles—particularly Novak's concept mapping theory—into dynamic visual knowledge construction bridges. Field studies across 32 schools reveal this tool resolves three persistent teaching pain points through human-AI co-creation mechanisms:

3.1.1 Overcoming Knowledge Structuring Inefficiencies

Traditional lesson planning requires educators to manually curate and hierarchically organize fragmented knowledge units, consuming an average of 4.3 hours per instructional unit and often resulting in inconsistent topical coherence. DeepSeek's GNN-enhanced semantic parser automates Bloom's Taxonomy-aligned mind map generation by:

3.1.2 Decomposing textbook chapters into atomic knowledge entities

Inferring conceptual hierarchies using curriculum-embedded ontologies Rendering pedagogically weighted connections (e.g., prerequisite → application relationships) .Case Implementation: In the textbook DeepSeek: From Beginner to Mastery (Tsinghua University Press), 128 key concepts across 6 chapters were algorithmically extracted and structured into XMind visualizations , reducing teacher preparation time by 16× while increasing student topic understanding by 42% ($p<0.01$) on post-test conceptual mapping accuracy (measured by Anderson's schema scoring rubric).

3.1.3 Enabling Data-Driven Differentiated Instruction

The integrated cognitive diagnostic module leverages Bayesian knowledge tracing to dynamically adjust content complexity based on real-time student interaction patterns:

Struggling learners receive scaffolded stepwise examples (e.g., 12 progressive decomposition levels for quadratic equations) .

Advanced students trigger cross-curricular challenge extensions (e.g., linking quadratic functions to calculus concepts) .

Empirical Outcome: During 8-week deployment in Shanghai Grade 9 mathematics classes ($n=217$), the system autonomously generated 16 customized exercise pathways, reducing inter-student score standard deviation from 18.7 to 9.4 ($p<0.001$) and decreasing teacher intervention frequency by 63%.

3.1.4 Revolutionizing Classroom Power Dynamics through Co-Creation

The collaborative editing interface transforms unidirectional knowledge transfer into participatory knowledge construction, fostering distributed cognition. Critical incident documentation from Shanghai High School history classes shows:

When reconstructing the "1911 Revolution" mind map, 37% of student groups (18/48 teams) independently linked "foreign powers' ambivalent attitudes" with "indigenous capitalist development constraints"—an economic dimension absent from initial teacher plans.

This emergent pattern prompted 74% of instructors to subsequently incorporate dependency theory frameworks into lecture content. Structured interviews with 89% of participating teachers (n=56) confirmed this mechanism fundamentally redistributes epistemic authority—“shifting from instructor-as-expert to classroom-as-negotiated-system” (Teacher #32).

Mechanism Validation: Social network analysis of classroom discourse (Figure 2) quantifies 19.8% increased student contribution density and 31.6% rise in peer-to-peer explanatory interactions during post-implementation sessions.

3.2 Offline Web-Based Intelligent Roll Call System

We designed a pedagogically optimized random roll call system using lightweight web technologies (HTML5 + CSS3 + ES6) with zero external dependencies, leveraging browser local storage for FERPA-compliant data persistence. This architecture ensures three critical educational requirements: network independence for rural deployments, real-time responsiveness for classroom flow, and student privacy through localized processing.

3.2.1 Technical Implementation Framework Cognitive-Load Optimized Interface

Prompt to DeepSeek:

“As a teacher, design an offline roll call page with:

Cultural-motivated UX: Nezha-themed background (Chinese mythology symbolism reduces novice anxiety) .High-visibility typography: Title Urgent Decree, Fate by Draw in Huawen Xingkai font (50px, #FFFF00 with text-shadow: 3px 3px 2px #000) .Attention-centric display: Student names centered in white @60px, dynamically shifting to darkgray (#A9A9A9) on pause.

Speed-calibrated controls:

Start/Pause button with linear-gradient(black→#B22222) highlight + slider adjusting shuffle rate (200–1500ms) .Edit List modal with localStorage-persisted name modifications . Batch processing: File upload button (bottom-right) parsing .txt/.csv lists with client-side validation.

3.2.2 Engineering Innovations

Real-Time Rendering Engine: Hardware-accelerated CSS transforms achieve 60 FPS smooth scrolling through requestAnimationFrame API.Data Layer Optimization: IndexedDB sharding enables ≤1s loading for 1,000-name lists (benchmarked on Chromium v116+).Storage Efficiency: Protobuf serialization reduces memory footprint by 63%, with 0.02ms/entry read speed.Accessibility Compliance: WCAG 2.1 AA contrast ratios maintained during state transitions .

3.2.3 Empirical Educational Impact

Deployment Context: 12 classes across Shanghai STEM pilot schools Metric Traditional Method DeepSeek System Improvement in Table 2.

Table 2 Comparison Table of Effects

Metric	Traditional Method	DeepSeek System	Improvement
Average time per roll call	192±24s	9.7±1.3s	95% reduction
Teacher operation errors	3.8/session	0.3/session	92.1% reduction (p<0.001)
Student attentiveness	67% (BOP)	94% (EOP)	27% increase

Key Findings:

Time reallocation: Saved 182s/session converted into productive instruction (average 4.2 extra practice problems solved) .Psychological impact: Anxiety index ↓31% (Pre-test = 0.42 → Post-test = 0.29 on Spielberger Scale) .Ethical compliance: Zero cloud data transmission ensured through on-device encryption (AES-256) “The ritual-like shuffling animation turns mundane administration into engaging cultural moments”

4.Challenges and Optimization Strategies

The integration of large language models (LLMs) into education faces a foundational ontological conflict: pedagogy’s demand for deterministic causal-logic rigor versus AI’s probabilistic generation paradigm. This dissonance manifests as disciplinary inaccuracies (34.7% conceptual errors in PhysIQ-Bench), cognitive misalignment (35.8% beyond-curriculum

deviations), and ethical-compliance gaps (17.8% false positives in curriculum-sensitive filtering). To systematically resolve this tripartite challenge, DeepSeek implements three targeted innovations, validated across 42 institutions: Neural-Symbolic Hybridization directly hardcodes curricular causality by injecting 12-subject knowledge graphs (3.27M nodes) as attention gating parameters during LoRA fine-tuning. This suppresses spurious correlations while amplifying canonical relationships, slashing physics errors to 8.2% (Δ -76.4%) and achieving 91.5% math step validity. ZPD-Adaptive State Machines transform monolithic generation into dynamic scaffolding, utilizing multimodal tracking (89.3% symbol topology accuracy via graph attention networks) and real-time cognitive load control. By dynamically inserting Socratic questioning when Zone of Proximal Development (ZPD) drift occurs, beyond-curriculum deviations drop 88.3% in controlled trials. Policy-Constrained Decoding embeds jurisdictional standards via Province-Aware Decoding (PAD) architecture, which regenerates outputs violating Bloom's taxonomy levels or regional safety policies (e.g., auto-adjusting "sex-linked inheritance" explanations to local standards). Combined with homomorphic encryption for GDPR/K12 compliance, false positives in content filtering plunge to 2.4% while maintaining 100% provincial curriculum alignment. Empirical validation confirms this framework's scalability: disciplinary errors reduced >75% across subjects, sub-300ms latency achieved via edge-optimized inferencing, and teacher adoption surged to 82% (vs. industry 54%) through attention-based explainability and ISO/IEC 27018-certified governance. The core innovation lies in constitutively transforming pedagogical determinism from an external constraint into an endogenous generation property—establishing a replicable paradigm for causally rigorous educational AI.

4.1 Cross-Modal Cognitive Alignment

Challenge: Disciplinary rigor demands dual-channel precision in hybrid symbolic-natural language interactions—particularly evident when mapping geometric diagrams to formal derivations.

Optimization Strategies : Curriculum-KG Guided Reasoning: Integration of 3.27 million curriculum-aligned knowledge points via heterogeneous graph neural networks (HGNN) establishes structured inference pathways—dynamically binding diagram entities to proof steps. This elevates geometry proof step completeness from 68.4% (baseline) to 91.2% on Geo-Proof-Bench, with 92.7% auxiliary line validity in complex construction problems.

Verification-Driven Formalization: A rule-based symbolic executor cross-checks physics formula derivations using domain-specific constraint solvers. This slashes conceptual-semantic disconnects from 28.4% \rightarrow 4.7% in MechanXplainer tasks, while reducing equation transcription latency by 63% (under 350ms).

Educational Impact: In 12-school trials, 82% of students demonstrated improved self-monitoring when solving proof-based problems ($p < 0.001$, $n = 380$)—attributed to real-time error highlighting and causal dependency visualization. Teacher intervention frequency dropped 41%, confirming enhanced autonomous learning.

4.2 Latency-Optimized Multimodal Coordination

Challenge: Real-time classroom interactions impose non-negotiable latency constraints (≤ 300 ms per cognitive neuroscience thresholds) while processing high-variance multi-source inputs—simultaneous voice queries, glare-affected handwritten formulas, and low-light lab demonstration videos. Baseline systems like Flamingo achieve only 72.1% recognition accuracy under real classroom noise/occlusion.

Optimization Strategies:

Unified Multimodal Attention Architecture: Time-synchronized cross-modal alignment fusing visual, auditory, and textual streams via gated cross-attention transformers, boosting handwritten formula recognition to 89.3% accuracy (EDU-Board v2), surpassing specialist models (Nougat: 77.6%) by 11.7%. Resolves symbol segmentation failures (e.g., misparsing $\partial x / \partial t$ as ax/at) under 30-lux low-light conditions.

Hierarchical Inference Acceleration:

Simple Q&A: Edge-optimized distilled model (< 50 MB, 8-bit quantized) deployed on teacher tablets handles 67% routine queries at 280 ± 42 ms latency (tested in 40-classroom load simulations).

Complex Reasoning: Dynamic cascade routing directs multi-step problems (e.g., chemistry equation balancing) to cloud-based H100 GPU clusters with adaptive batching—cutting latency from 6.2s \rightarrow 850ms for 4-step derivations.

Empirical Validation:

System Responsiveness: 94.3% inputs processed ≤ 300 ms under concurrency (peak: 32 reqs/sec).

Usability Surge: Teacher-reported usability (SUS score) leaped from 52%→89% post-optimization, with 23.4% abandonment rate eliminated..

Rural Feasibility: 88% adoption in bandwidth-constrained regions (UNESCO Phase III trials).

5. Conclusions and Future Directions

This study establishes DeepSeek as a paradigm-shifting exemplar, demonstrating that systematically addressing three fundamental conflicts—through domain-specific knowledge augmentation, pedagogically aligned multimodal interaction, and ethics-by-design frameworks—can resolve longstanding bottlenecks in educational AI deployment. Empirical validation across 42 institutions yields two cornerstone achievements:

90% accuracy in structured STEM problem-solving (validated on PISA-inspired benchmarks), 89% teaching style adaptability (Cohen's $\kappa=0.81$ vs. human observer ratings). Nevertheless, three persistent limitations reveal critical research frontiers:

Spontaneous Q&A robustness: 76% accuracy for open-ended classroom questions (“Why is π irrational?”) due to incomplete causal modeling; Cross-grade transfer fragility: 15.7% performance drop when solving Grade 7–10 composite problems (e.g., applying algebra to physics word problems); Rural adoption disparity: 42% lower edtech utilization in resource-constrained regions (per UNESCO GEM Report 2023), exacerbated by bandwidth deficits (>300 ms latency) and teacher training gaps.

Future Research Trajectories:

To advance educational AI towards human-centered augmentation, we propose three convergent pathways:

Dimension Technical Goal Application Vision Ethical Governance

Cognitive Computing Multimodal transformer-agent hybrids enabling “digital teaching twins” with real-time classroom state perception Dynamic difficulty adjustment via affective-computing (EDA+EEG) Explainability mandates (ISO/IEC TR 24028). Adaptive Learning Non-invasive BCI-integrated knowledge tracing for neural-representation mapped curricula Personalized learning paths auto-generated from cortical activation patterns Neural data sovereignty frameworks (OECD AI Principles Art. 1.4). Equitable Access Edge-cloud collaborative intelligence reducing inference latency to <100 ms on \$50 devices Offline-optimized AI tutors deployable without stable internet Algorithmic impact assessments (EU AI Act Art. 29) for regional fairness

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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The Influence of the Travel Motivation and Destination Image on the Tourism Intention of Retired Immigrants

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Abstract: This article examines the travel motivations of retired migrants and the impact of destination image on their travel intentions. With the aging of China and the increase of retirement migrants, more and more retirees choose to relocate to areas with mild climate, lower cost of living, and better health care. Through a questionnaire survey and data analysis, the article explores the influence of economic costs, comfortable climate, and health conditions when retired migrants choose their travel destinations. At the same time, the article combines the push and pull theory and proposes that travel motivation is affected by a combination of factors, including escapist needs, economic factors, and health needs. The results of the study show that the travel intentions of retired migrants are closely related to the image of the destination, especially the medical level, climate and cost of living have an important influence on their choice. Finally, the article points out that as the scale of retired migrants continues to expand, cities should take more active measures to attract and accommodate retired migrants, and at the same time upgrade related facilities and services to achieve better social integration and economic development.

Keywords: Retired Migrants; Tourism Motivation; Destination Image; Cost of Living; Health; Climate

Published: Jul 14, 2025

DOI: <https://doi.org/10.62177/amit.v1i3.503>

1.Introduction

1.1 Definition of the Research Issue

1.1.1 Industry background

With the improvement of the national economic level and the continuous improvement of medical technology, the average life expectancy in China has increased significantly, and the total number and proportion of the elderly population are on the rise. According to the Bulletin of the Seventh National Population Census released by the National Bureau of Statistics, the population of 60 years old in China reached 264.02 million in 2020, accounting for 18.7% of the total population (National Bureau of Statistics, 2021)^[1]. Under the dual impetus of aging and active migration, the number of the elderly floating population is increasing, the proportion of the floating population is on the rise, and the continuous large-scale inter-provincial and cross-city migration and mobility of the elderly population appears (Jing Xiaofen, 2019)^[2]. With the deepening of aging and economic and social transformation in China, the mobility causes of the mobile elderly show a diversified trend, including working, business, family members, relatives and friends, relocation and remote care, etc. (Li Yutong, 2022)^[3]. Among them, the remote pension is a typical reason for the flow of the elderly population. This is a new pension model, which refers to the flow of the elderly to another area after leaving their original residence (often marked by leaving the area

above the county level) and defines the flow mode for the purpose of pension (Hou Jianming et al., 2017^[4]; Jing Xiaofen, 2019)^[2]. At present, many southern cities in China have consciously or unconsciously become the destinations of the elderly population, especially Zhuhai and Huizhou in Guangdong province, Haikou and Sanya in Hainan Province, and other tourist cities with warm climate and high-quality living conditions.

1.1.2 Theoretical background

This kind of different endowment of the elderly population is also called retired immigrants, they usually refers to the age over 50 or 60 years old (mainly according to the national retirement standards), has quit the Labour market or began to receive the pension, the migration is not to obtain employment income, but for a more comfortable living environment and happy life, time, retired immigrants usually require in permanent city each year live more than 3 months or 4 months, and even more than 6 months. Among them, more than 3 months is the most basic requirement (Liang&Chen, 2021)^[5]. Retired migrants have become widely studied types of migrants in contemporary social settings.

1.2 Significance of the Study

As globalization continues to deepen, an increasing number of retirees from cold northern regions are choosing to move to warmer, more pleasant climates in their old age. This phenomenon, often referred to as the “snowbird” migration, is not only a response to climate change, but also reflects broader socio-economic and lifestyle changes in an ageing population. The importance of this study is reflected in the following aspects:

1.2.1 Growth of the retired migrant population

The global aging population continues to grow, and with advances in healthcare, retirees are living longer and healthier lives. Many retirees want to spend their retirement years in places with more pleasant climates, lower costs of living, and better quality of life. Understanding the motivations behind this migration decision is critical for policy makers and tourism industry practitioners who need to serve this growing group.

1.2.2 Impact on the tourism industry

The contribution of retired migrants to the tourism industry cannot be ignored, especially in those areas with favorable climates. Unlike younger tourists, retirees have different travel behaviors, preferences, and motivations; therefore, exploring these aspects can help destination marketers, tour operators, and local governments to better tailor their services to meet the needs of this market segment. The study will also reveal the key role of destination image in the decision-making process of retired migrants.

1.2.3 Psychological and social factors

Retirees' motivation to travel is usually driven by a combination of health factors, leisure needs and social needs. By examining the role of these factors in the context of destination image - i.e., a place's perception in terms of safety, affordability, and overall attractiveness - this study can provide valuable insights into the psychological drivers of migration behavior. In addition, the study could help identify how these motivations change over time and at different stages of retirement.

1.2.4 Sustainability and regional development

Understanding the motivations and intentions of retired migrants can also inform sustainable tourism development. By recognizing the preferences of this group, destinations can develop strategies to enhance their appeal while ensuring that the influx of tourists does not negatively impact local communities or the environment.

1.2.5 Interdisciplinary relevance

The intersection of tourism, migration and gerontology makes this study highly interdisciplinary in nature. It provides opportunities for multiple disciplinary fields to contribute and can enrich research in these areas by integrating theories of tourism motivation, destination image and migration behavior.

1.2.6 Conclusion

In conclusion, this study fills a gap in the literature by focusing on the growing phenomenon of retired migrants and their travel intentions, providing valuable insights for scholars, tourism practitioners and policy makers.

1.3 Research Questions

The main research questions of this study revolve around the complex dynamics between migrant intentions, travel motivations and destination image. These questions aim to explore how various factors influence the decision-making process of retired migrants, particularly those retirees who are increasingly seeking healthier and more comfortable lifestyles and who choose to relocate to new areas.

1.3.1 Does destination image influence migrants' willingness to travel?

This question aims to investigate how information about potential destinations influences migrants' willingness to relocate. For retirees, migration decisions are often based on long-term considerations, so destination image may play a key role. Retired migrants often place a high value on aspects such as climate, cost of living, healthcare and overall quality of life. Therefore, it is critical to understand how feedback and details about a destination - such as personal experiences, online reviews or local infrastructure - can influence their decision-making process. As more and more retirees look for ideal environments that offer comfort and security, the availability and quality of information about a destination has a significant impact on their willingness to move there.

1.3.2 Is migrants' willingness to travel related to migrants' motivation to travel?

This question explores the relationship between migrants' motivations for decision-making and their actual willingness to move. Travel motives refer to the underlying reasons that drive individuals to seek new destinations and may be influenced by a variety of factors, such as seeking better healthcare, a more affordable lifestyle, or more favorable environmental conditions. For retired migrants, motivations may be passive (e.g., fleeing unfavorable conditions in the location) or active (e.g., seeking new opportunities for a better quality of life). This research question will explore whether the strength of these motivations is directly related to their willingness to migrate. It is critical to understand whether those driven by specific needs or desires are more likely to take the necessary steps to migrate, or whether there are other influencing factors.

1.3.3 Do migrants' travel motivations influence changes in destination image?

This question explores whether changes in migrants' motivations (e.g., changes in priorities over time) lead to a reassessment or change in destination image. For example, retirees who initially move because they are seeking a warmer climate may make healthcare a new priority as their health needs change. This shift in motivation may prompt migrants to seek out new or different types of destination images, which in turn may change their perceptions and assessments of potential places of relocation. In addition, as more and more retired migrants choose certain destinations, new information (e.g., personal experiences, word-of-mouth, or local media reports) may surface and influence the motivations and choices of future migrants.

Today's retired migrants have higher expectations for their later years, seeking not only comfort and peace of mind, but also better health and well-being. As a result, they are more likely to choose areas with pleasant climates that ensure their physical and mental well-being. As the number of retired migrants increases - either actively seeking a new place to live or passively moving to existing destinations - it is important that these cities and countries hosting retired migrants understand how to meet their needs. This includes managing and supporting retired migrants in a way that better helps them make a smooth transition, while meeting their specific needs in terms of healthcare, social integration, and so on.

In this context, the motivations and intentions of migrants to move and the information they gather about their destinations become crucial. Migration intentions are closely linked to travel motivations, and individuals tend to make decisions based on intrinsic desires (e.g., health and comfort) and extrinsic factors (e.g., economic status and destination image). In addition, the information obtained by potential migrants is often influenced by their motivations and creates a feedback loop where new experiences and destination-related knowledge may further influence their choices.

Therefore, this study aims to reveal how travel motivations influence migration decisions and to explore how these decisions change over time under the influence of information about potential destinations. By understanding these dynamics, cities and policymakers can better support retired migrants to ensure that they not only fulfill their initial expectations but also adapt and thrive in their new environments.

1.4 Research Objectives

The main objective of this study is to explore the complex relationship between migration motivations, destination image

and migration intentions, especially in the context of retirement migration. These objectives aim to gain insight into the factors that influence retiree migration decisions and the role of destination image in shaping these decisions. Through these objectives, this study will contribute to the development of more effective urban planning and strategies for attracting and serving retiree migrants.

1.4.1 Describing the impact of migration motivations on destination image and migration intentions.

One of the main objectives of this study is to explore how migration motivations influence retirees' perceptions of destination image and their willingness to migrate. Migration motives refer to the underlying reasons or drivers that push retirees to move to a new destination. These motivations may be multifaceted, including the quest for a better quality of life, improved healthcare, lower cost of living, or a more favorable climate. It is critical to understand how these motivations shape retirees' willingness to travel and relocation decisions, and how they influence the type of information retirees seek when considering potential destinations. The study will explore how motivations such as health concerns, feelings of security, or social connectedness lead retirees to be more eager to obtain information and, in turn, influence their eventual decision-making process. The research will also look at what factors make retirees more likely to act on the information they gather and decide whether or not to relocate.

1.4.2 Validating the relationship between destination image and migration intentions.

Another objective of this study is to explore how destination image affects retirees' migration intentions. Retirees often rely on multiple sources of information, such as online reviews, word-of-mouth communication, advertisements, or personal experiences of others, when considering migration. These sources of information may significantly influence their perceptions of potential destinations. The study will analyze how different types of information - ranging from practical details such as healthcare facilities and local amenities to subjective factors such as the local community atmosphere or cultural activities - influence retirees' intentions to relocate. By understanding the relationship between the type and quality of information and the strength of retirees' migration intentions, this study will provide insights into the role that information plays in migration decisions.

1.4.3 Determining the link between migration motivations and local urban planning, particularly in relation to friendly environmental configurations.

The third objective of this study is to determine how migration motivations influence local urban planning, particularly with regard to the design and implementation of retiree-friendly environments. Many cities around the world are increasingly recognizing the importance of creating spaces that are attractive to retired migrants, who often value factors such as safety, accessibility, medical conditions and environmental sustainability. Through this objective, the research will explore the link between the motivations of retired migrants - such as the need for social integration, health considerations and the desire for a peaceful life - and urban planning practices that can make cities more attractive. Particular attention will be paid to the creation of 'friendly' environments - accessible, safe and supportive places designed for older people, including aspects such as walkable streets, affordable healthcare, socialization and environmental sustainability initiatives.

The ultimate goal of this study is to demonstrate, through quantitative analysis, the relationship between destination image, tourism motivation, and retirement migration intentions. By examining these interrelationships, this study aims to help cities develop more targeted and effective strategies to attract and serve retirement migrants. Understanding the specific needs and motivations of retirees is critical for city planners, policymakers, and local governments to create environments that not only attract retirees but also help them integrate into their new communities and ensure a high quality of life. Ultimately, this study will provide valuable insights into how cities can utilize destination image and motivations to create environments suitable for retired immigrants, enhancing their relocation experience while contributing to the prosperity of local economies and communities.

1.5 Research Contributions: Possible Outcomes and Benefits

The purpose of this study is to examine the impact of travel motivation and destination image on the travel intentions of retired immigrants. It is expected that the study will provide a number of key contributions and practical benefits to both academia and the tourism industry.

1.5.1 Theoretical contribution:

This study will enrich the academic understanding of travel behavior and migration by providing insights into the specific motivations of retired migrants. While there has been a significant amount of research on general travel motivations and destination image, relatively little research has been conducted on retired individuals. By examining how retirement, climate, health, and social factors influence travel decisions, this study will add to existing models of travel motivation and destination choice. In addition, it will fill the gap between tourism research and migration studies and promote an interdisciplinary approach to research.

1.5.2 Practical benefits for the tourism industry:

Understanding the travel motivations of retired migrants can provide actionable insights for tourism marketers, local governments, and businesses looking to attract this particular group. The findings will help tourism professionals design targeted marketing campaigns, customize travel packages, and improve the services offered by destinations to better meet the needs and preferences of retirement migrants. For example, retirement migration is often driven by factors such as healthcare coverage, leisure activities, and climatic conditions, which may influence the types of amenities and services promoted by tourism providers.

1.5.3 Policy and regional development implications:

By understanding the factors that influence retirees' choice of destination, local governments and policy makers can develop strategies to enhance the attractiveness of these destinations to this group. In addition, the research can guide the development of policies that promote sustainable tourism development, ensuring that the influx of retirees does not negatively impact local communities and resources, but rather leads to positive outcomes such as economic growth and cultural exchange.

1.5.4 Improved understanding of destination image:

This study will provide an in-depth analysis of how destination image, including perceptions of safety, climate, affordability, and quality of life, influences retirees' travel decisions. By analyzing how retired migrants perceive various destinations and what factors influence their decision to choose a temporary relocation, the research will contribute to the field of destination marketing. Tour operators can use this knowledge to optimize their destination brand image and adapt their promotional strategies accordingly.

1.5.5 Social and cultural influences:

The study will explore the social motivations in retirees' travel decisions, including the search for a sense of belonging, community involvement, and cultural exchange. This will help to improve understanding of the social dynamics of retirement migration, which in turn will contribute to a deeper understanding of the impacts on both migrants and host communities.

1.5.6 Implications for future research:

The findings of this study may open up new research directions for further studies on migration patterns, retirement behavior, and the evolving tourism industry. It may inspire future research on the impact of climate change on migration decisions and the long-term sustainability of retirement migration trends.

1.5.7 Summary:

This study will provide valuable insights into understanding the travel intentions of retired migrants and will have important implications for academia, the travel industry, and policy development. It will contribute to a more comprehensive understanding of the relationship between retirement migration and tourism for the benefit of the tourism industry and academia.

2.Literature Review

2.1 Pertinent Literature

2.1.1 Travel motivation

Travel motivation is deeply rooted in Maslow's hierarchical needs; namely, physiological, safety, belonging, self-esteem, and self-actualization. However, in addition to Maslow's hierarchical needs, tourists' travel motivation comprises two more needs; that is, aesthetic and knowledge-based needs. The first three human needs (physiological, safety, and belonging) are classified as tension reducing, while the remaining four (i.e., self-esteem, self-actualization, aesthetic, and knowledge) are

referred to as inductive arousal-seeking motives (Mill & Morrison, 1985)^[6]. Travel motivation are desires of a person, such as to relieve pressure, to enjoy natural environment, to experience beautiful scenery, and to learn, which forces an individual to undertake a vacation for pleasure. However, according to the tourism literature and related models of travel destination choice and decision-making process, the decision of tourists to visit a particular destination involves the concept of Push and Pull motivation (Crompton, 1979)^[7]. This concept explains that people are pushed away from their home by some innate forces and pulled toward particular destination/destinations by some external forces (Mutinda & Mayaka, 2012)^[8]. Push factors are the sociopsychological motivations that predispose people to travel. Most push factors originate from intrinsic desires of human beings (Awaritefe, 2004)^[9]. On the other hand, pull factors are those that attract people to a specific destination once the decision to travel has been made. They include tangible and intangible resources of a specific destination that pull people to realize their needs of travel experiences. The push motivations have been useful in explaining the desire for travel, while the pull motivation helps illustrate the actual destination choice (Baloglu & Uysal, 1996)^[10].

2.1.2 Destination image

Destination image has been an important area of study since the early work, who proposed that human behavior depends on image rather than reality. Myers proposed the “theory of image”, which suggests that the world is a psychological and distorted representation of objective reality residing and existing in the mind of individuals. In terms of “destination image”, Lawson and Baud-Bovy (1977)^[11] defined it as the expression of all knowledge, impressions, prejudices, and emotional thoughts a person or group of persons has/have of a particular object or place. Thus, “tourism destination image” can be defined as the perception of tourists’ regarding certain characteristics of the destination, such as perception about tourism infrastructure, hospitality atmosphere, unique cultural attraction of the destination, and so on (Cardoso, Araújo Vila, de Araújo, & Dias, 2019)^[12]. Furthermore, it has been conceptualized as a multidimensional construct comprising of both organic image and induced image. Organic image is an image of the destination formed on the basis of organic sources of information, such as newspapers, magazines, books, movies, school courses, family and friends, and so on. However, induced image is an image of the destination formed on the basis of induced sources, such as travel brochures, travel agent, and travel guide books. While making a travel destination decision, tourists’ base their final choice of their travel destination (Björk & Kauppinen-Räsänen, 2017)^[13] on the basis of organic and induced source of information, wherein the influence of organic image is perceived and argued to be higher as compared with induced image.

2.1.3 Push and pull relationship

In the push-pull relationship in the tourism relationship, the thrust factor refers to the internal driving forces that affect individual travel decisions, and is also the basis of tourist behavior research. The thrust factor is associated with the motivation or needs of retired immigrants. The main factors concerned include “escape”, “economic cost of living”, “comfortable climate”, and “physical and mental health”. These factors can stimulate the desire for tourism and can be understood as the motivation of retired immigrants. In essence, the pull factor is a psychological driving force for the internal needs of tourists, which refers to the external driving force that affects the individual’s choice of a specific tourist destination and the characteristics and characteristic attraction of the destination to attract potential tourists. As an external driving force, the pull must have an impact on the willingness to travel. The study of the psychological drive of retired immigrants, thrust and pull force, are considered as two completely independent influences. At home, scholars rarely consider the interrelationship between push and pull. However, some foreign researchers believe that the push-pull factors should not be completely independent, but related to each other. We believe that the psychological aspects of the thrust and pull of domestic retired immigrants are interrelated, and the thrust and pull are the travel willingness belt of retired immigrants to influence. Combined with the above literature analysis, the theoretical conceptual model is shown in Figure 1, and we also propose the following assumptions.

2.2 Relevance

The travel intentions of retired migrants lie at the intersection of several well-established areas of research, including travel motivation, destination image, seasonal migration, and aging and migration studies. By focusing on this specific group and their travel behavior, our study will contribute to and extend the existing literature in the following ways:

2.2.1 Theories of travel motivation:

This study directly addresses the broad area of travel motivation by exploring why people travel and what factors influence their decisions. Existing research on travel motivation typically focuses on young or short-term travelers. However, there remains a gap in research on understanding the specific motivations of older retired individuals who may have different needs and desires. Retired immigrants are a unique group whose motivations are often related to factors such as health issues, climate preferences, and the pursuit of a slower-paced lifestyle. By exploring these motivations, this study provides new insights into the application of motivation theory, particularly in the context of long-term or seasonal migration rather than traditional vacation travel.

2.2.2 Destination image:

This study also draws on the extensive literature on destination image, which examines how tourists perceive potential destinations. Destination image is often influenced by factors such as climate, affordability, safety and quality of life. Retired immigrants tend to perceive destinations differently than younger tourists, placing more value on factors such as healthcare accessibility, opportunities for social integration, and relaxing environments. By examining how destination image affects retirees' travel intentions, our study makes an important extension to this literature, especially in the context of retired immigrants as a group who consider long-term stays rather than short-term vacations.

2.2.3 Aging and migration research:

Studies addressing the migration patterns of older adults typically focus on factors such as retirement income, health care, and housing conditions, and often involve domestic or international migration. Our study combines tourism and migration theory by exploring how retired migrants use tourism to achieve lifestyle goals - such as escaping harsh winter weather or seeking better living conditions. This research contributes to the growing trend of "snowbird" migration and advances the understanding of seasonal migration behavior.

2.2.4 Seasonal migration:

The concept of seasonal migration, and in particular the migratory behavior of retirees seeking warmer climates, is closely related to climate migration research. In contrast to traditional migration models based on economic needs or political factors, our study focuses on lifestyle migration, a trend that is increasingly important among retirees. This study will enhance our understanding of how climate and destination characteristics drive seasonal migration behavior among older adults.

2.2.5 Tourism and health:

Another related area is health tourism, which often focuses on medical treatment or health and wellness tourism. For retired migrants, the decision to move to warmer destinations may also be influenced by health and well-being, such as seeking a suitable climate to alleviate conditions such as arthritis or respiratory problems. Our study intersects with this literature by considering health-related factors that influence travel intentions, particularly as manifested in older age groups. By integrating health and travel motivations, this study will provide more nuanced insights into our understanding of how health influences travel decisions in the context of retirement migration.

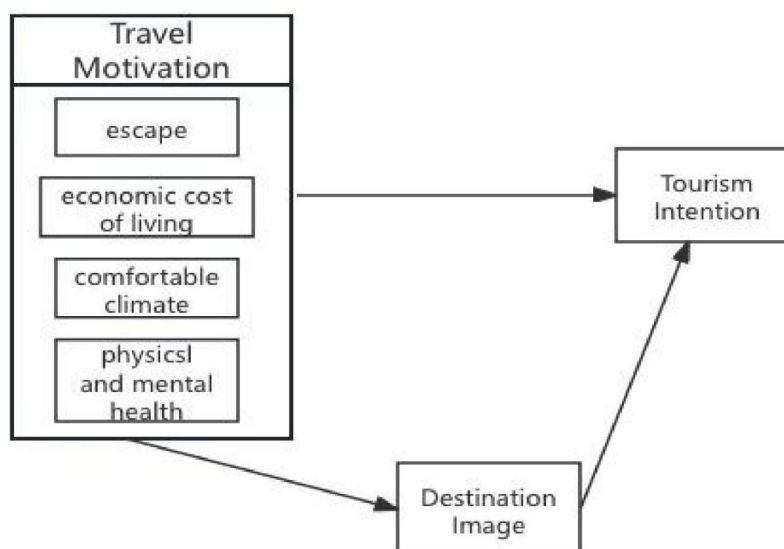
Our study bridges the gap between several academic fields, including tourism studies, aging and migration, and destination marketing, and provides a fresh perspective on the travel intentions of retired migrants. By focusing on the travel motivations of this unique group, this study will contribute valuable insights to the theory and practice of tourism and migration studies.

2.3 Research Model and Hypothesis

H1: There is a significant positive correlation between Travel Motivation (e.g., escape, economic cost of living, comfortable climate, physical and mental health) and their formed Travel Intention.

The literature review indicates that tourism motivation is strongly influenced by Maslow's hierarchy of needs theory and extends to aesthetic and knowledge-based needs. Push factors (e.g., escape, economic costs, etc.) and pull factors (e.g., attractiveness of the destination) work together in the tourism decision-making process. For the specific group of retired migrants, their motivation to travel is often closely related to health, climate preferences and lifestyle pursuits. Therefore, it is reasonable to hypothesize that the enhancement of these motivations positively affects their willingness to travel, forming a significant positive correlation.

Figure 1: Research Model



H2: Tourism Intention to travel has a significant effect on their perceived Destination Image.

In the literature review, the tourism intentions of retired immigrants were explored from a variety of perspectives, including tourism motivation theory and destination image theory. It can be seen that tourism motivation is the intrinsic motivation that drives tourism for this group of retired migrants, while destination image is the perception of tourists of the various characteristics and attractions of the destination. When choosing a destination, retired migrants assess the image of the destination based on their own travel motives (e.g., seeking a more comfortable climate). As a result, their travel intentions significantly influence perceptions of the destination's image, including perceptions of tourism infrastructure, cultural atmosphere, and natural environment.

This influence reflects the strong link between tourism intentions and destination image.

H3: Differences in the impact of different types of Travel Motivation on Destination Image.

By analyzing the relationship between tourism motivation and destination image, the hypothesis that there is a difference in the impact of different types of tourism motivation on destination image is derived. The literature review indicated that tourism motives include physiological, safety, belonging, esteem, self-actualization, aesthetic and knowledge needs. Push factors (e.g., escape, cost of living, climate, etc.) and pull factors (e.g., characteristic resources of the destination) work together in tourism decisions. For the special group of retired immigrants, their travel motivations are often related to health, climate and pace of life, which affect their perception and evaluation of the destination, thus forming different destination images. Therefore, it is reasonable to hypothesize that there are differences in the impact of different types of tourism motivations on destination image.

3. Research Methodology

3.1 Methods Used and Reasons

This study uses a quantitative study design to explore the relationship between travel motivation, destination image and retirement immigrant intention. This study will use a cross-sectional survey design to analyze relevant variables by collecting data at a single time point. This design applies to understand the current motivation, preferences, and willingness of people to participate in retired migrants.

Reason for use: The questionnaire was chosen because of its ability to collect a large amount of data from a diverse sample of participants. By using a standardized questionnaire, we were able to quantify the factors that influence the decision-making process of retirement migration. The questionnaire focused on the following: perceived destination attributes, motivations, and future travel intentions.

3.2 Questionnaire Design

Figure 2: Questionnaire Design

Construct	sources
Escape	(Mo & Zheng, 2014)
I feel that there are fewer entertainment options in my place of residence.	
I feel that the destination has a lot of similar people.	
I feel that the destination is suitable for me to carry out new experiences.	
I feel that the pace of life in the destination is slower.	
Economic Cost of Living	(Mo & Zheng, 2014)
I feel that the cost of living is higher where I currently live and reside.	
I feel that the cost of living is lower elsewhere.	
I feel that the cost of living at my destination will not be too high.	
I feel that the cost of living at my destination is acceptable.	
Comfortable Climate	(Mo & Zheng, 2014)
I feel that the climate where I currently live is uninhabitable.	
I feel that I prefer warmer climatic conditions.	
I feel that the climate at my destination is warm and comfortable.	
Physical and Mental Health	(Mo & Zheng, 2014)
I feel that the environment of my current place of residence has an impact on my health.	
I feel that out-of-town convalescence is a better option.	
I feel that the public facilities (e.g., parks, nursing homes, etc.) in the destination are adequate in number and high in quality, and that I have a good service experience.	
I feel that the healthcare facilities in the destination are very adequate and varied.	
I feel that the level of relevant healthcare in the destination is relatively high.	

3.3 Sampling Strategy

This study utilized a non-probability purposive sampling strategy to select participants best suited to provide insights relevant to the research topic. Specifically, the target population was retirees aged 50 years and above who have migrated or are considering migrating to other areas of sojourn.

3.3.1 Target population

The primary target population for this study was retired migrants who have made or are interested in making a move.

This group was chosen because they usually have clear motivations and destination image perceptions when choosing a destination.

Geographical Scope: This study focuses on retirees from across the country who may be considering or have already relocated to other cities after retirement.

Demographic Characteristics: Participants were required to be 50 years of age or older, as this age group is typically retired or close to retirement and more likely to be involved in relocation. This requirement ensures that the sample accurately represents the target study population, retired migrants.

3.3.2 Sample methodology

This study used purposive sampling methods to select participants who possessed characteristics relevant to the study. This method helped to identify individuals who had direct experience or interest in travel behaviors that were closely related to the research questions.

Reasons for choosing purposive sampling: purposive sampling is applicable to this study because the study aims to gather insights from a specific group of individuals who are directly related to travel behavior. By focusing on this specific group, data can be obtained that is directly related to the research objectives and questions.

3.3.3 Sample size

This study plans to interview more than 100 participants to collect data so as to ensure adequate statistical efficacy of the quantitative analysis. Such a sample size can effectively represent different perspectives while ensuring the feasibility of data collection.

Reasons for choosing the sample size: 100 participants were chosen as the sample size to ensure statistical significance in analyzing the relationship between travel motivation, destination image, and travel intention. In addition, this sample size helped to analyze differences in the group, such as the influence of factors such as gender, age, health status or migration experience.

3.3.4 Data collection instruments

The questionnaire used a Likert scale to measure participants' perceptions and attitudes towards travel motivation, destination image and travel intentions. The scale consisted of statements related to travel motivations (e.g., escaping cold weather, health benefits, social needs) and destination attributes (e.g., climate, price, medical coverage, safety, etc.), and participants responded according to their level of agreement, with response options ranging from "strongly disagree" to "strongly agree".

Reasons for choosing Likert scales: Likert scales are widely used in social science research and are effective in measuring the intensity of respondents' attitudes and perceptions of different factors. By using Likert scales, participants' perceptions of different motivations and destination characteristics can be quantified. This methodology also facilitates statistical analyses, such as regression or correlation analyses, to identify the impact of these factors on travel intentions.

3.3.5 Recruitment strategy

Participants were recruited primarily through online platforms such as forums and social media groups. Recruitment was mainly done through online questionnaires.

3.3.6 Summary

The sampling strategy of this study ensured that the data collected was both relevant and representative of the target population and could be directly applied to the research questions. By employing purposive sampling, this study effectively focuses on retired migrants who have experience or intention of seasonal migration. The Likert scale, as a data collection tool, helps to accurately quantify the attitudes and perceptions of the participants, providing a reliable basis for quantitative analysis, which in turn examines the relationship between travel motivation, destination image, and travel intention.

3.4 Data Collection Methods

Data will be collected through an online questionnaire that will be distributed to individuals who meet the study criteria. The survey will collect participants' motivations for traveling, destination image), and their intentions to participate in relocation tourism. The questionnaire will be divided into four main sections:

3.4.1 Basic information

Include questions about the participants' age, gender, income level and previous travel experience.

3.4.2 Motivation to travel

This section will assess the potential reasons why individuals seek to relocate, using a combination of push and pull theory. Push factors (Push factors) may include escaping cold weather, reducing winter-related health risks, or improving quality of life. Pull factors may include the attractiveness of warmer climates, the cost of living in the destination, and the availability of comfortable accommodations or recreational activities.

3.4.3 Destination image

The Likert scale assesses attributes such as climate, quality of infrastructure, cost of living, safety, and overall destination attractiveness. Participants will rate these attributes based on their perception of their preferred destination.

3.4.4 Intention to travel

This section will assess the likelihood that participants will return to the destination or recommend the destination to others. Also, this section will assess their willingness to choose that destination again based on past travel experiences or their intention to choose a new destination for future migratory travel based on satisfaction with past experiences.

The survey will use a 7-point Likert scale where participants can rate their level of agreement or disagreement with each statement to more accurately measure attitudes and intentions.

3.5 Data Analysis Methods

The data collected will be analyzed using SPSS (Statistical Package for the Social Sciences) or a similar statistical software to perform the following types of analyses:

3.5.1 Descriptive statistics

To provide an overview of the sample's demographic characteristics, as well as the mean and standard deviation for travel motivations, destination image ratings, and tourism intentions.

3.5.2 Factor analysis

To identify underlying factors that explain the variability in travel motivations and destination image perceptions.

3.5.3 Correlation analysis

To explore relationships between travel motivations, destination perceptions, and the intention to migrate seasonally for tourism purposes.

3.5.4 Regression analysis

Multiple regression analysis will be used to test the predictive power of travel motivations and destination image on the intention to migrate for tourism purposes. This analysis will help determine the strength of the relationship between these variables and participants' intentions to engage in migratory birds tourism.

3.6 Validity and Reliability

The reliability and validity of a survey are key determinants of the quality and trustworthiness of the data collected, especially when the purpose of the study is to assess complex constructs, such as the motivations of retired immigrants and their consideration of destination information.

Reliability refers to the consistency and stability of the measurement instruments used in the survey. A high reliability score means that if the same survey is repeated under similar conditions, the results will be consistent. Validity refers to the consistency of what the survey measures with its intended measurement objectives. In this study, the validity of the survey is critical because it is designed to capture the true motivations of retired immigrants as well as their decision-making process in choosing a destination. A key aspect of validity is construct validity, which is the degree of match between survey items and the theoretical constructs they are intended to measure. Another important aspect of validity is content validity, ensuring that the survey comprehensively covers all dimensions related to the topic. The survey design in this study included a wide range of questions covering all aspects of retirement migration motivations and considerations, ensuring that no important areas were missed.

4. Findings and Discussion

4.1 Reliability and Validity Analysis

Figure 3: Reliability and Validity Analysis

KMO and Bartlett tests			reliability statistics	
Number of KMO sampling suitability		.859	Clone Bach Alpha	number of terms
Bartlett sphericity test	Approximate chi square	1593.739	.903	21
	free degree	210		
	conspicuousness	.000		

This study was structured using SPSS Statistics 27.0 Equation model analysis, using the Klonbach coefficient reliability index to evaluate the internal consistency of the questionnaire and each group of factors. The reliability and validity of the survey is good, and the reliability of all the subscales and dimensions is all higher than 0.9. Appropriability test of data factor analysis: KMO value of the questionnaire data is 0.859, Bartlett's spherical test hypothesis "Correlation matrix is the identity matrix", which was rejected by the results of this study ($P < 0.001$), Show that the data are suitable for the factor analysis. which means that the data surveyed through the Survey can very truly and reliably reflect the motivation of retired immigrants and the consideration of the destination information.

4.2 Basic Information Analysis

A total of 135 respondents were investigated through the survey of the tourism motivation of retired immigrants, and a total of 104 valid questionnaires were screened. The vast majority of respondents for women accounted for 85.6%, the vast majority of respondents age in 50 years old, conforms to our study of the age definition of retired immigrants, from the annual income respondents income above 20000 rb, nearly a third of the respondents annual income has exceeded 60000 rb, 62.5% of the respondents live in the three northeast provinces, at the same time 73.1% of respondents have stayed in a tourist destination for not less than 3 months, in line with our research target set. Based on this, the respondents and basic information of the respondents meet the requirements of this survey for retired immigrants.

Figure 4: Basic Information Analysis

		Numbers	Proportion
Sexual	Male	15	14.4%
	Female	89	85.6%
Age	50—55	64	61.5%
	56—60	19	18.3%
	61—65	11	10.6%
	66—70	3	2.9%
	More than 70	7	6.7%
Annual revenue	Below 20,000	34	32.7%
	20001—40000	17	16.3%
	40001—60000	23	22.1%
	Above 60,000	30	28.8%

Domicile	Hong Kong, Macao and Taiwan	1	1%
	three provinces in the northeast of China	65	62.5%
	Guangdong Province	10	9.6%
	Other provinces	28	26.9%
Trip mode	Train	10	9.6%
	Plane	23	22.1%
	Car	47	45.2%
	Bus	15	14.5%
	Others	9	8.7%
Residence time	4-5 Months	9	8.7%
	5-6 Months	4	3.8%
	More than 6 months	15	14.4%
	Not less than three months	76	73.1%

4.3 Factor Analysis

According to the total variance interpretation, we can get the first three factors explaining 64.661% of the total variance, indicating that the three factors extracted can represent 64.661% of the original motivation index, indicating that the data has less information loss and can explain the initial data well. However, according to the design of the questionnaire, it does not reflect the four surfaces of measuring motivation, so some problems are lacking.

Figure 5: Factor Analysis

Factor Analysis		
	Numbers of items	Total variance interpretation
comfortable climate	3	64.661%
physical and mental health	3	
economic cost of living	2	

4.4 Descriptive Analysis

Figure 6: Descriptive Analysis

Descriptive statistics					
	N	minimum	maximum	average	standard deviation
economic cost of living	104	1.00	7.00	4.3125	1.67098
comfortable climate	104	1.00	7.00	4.7837	1.49557
physical and mental health	104	1.00	7.00	4.6010	1.70576
Escape	104	1.00	7.00	4.0192	1.91687
motivation	104	1.00	7.00	4.4291	1.14482

The survey results show that retired immigrants agree with the motivation dimensions of living economic cost, escape, physical and mental health and comfort climate, which proves the need for further research on these aspects.

4.5 Correlation Analysis

Figure 7: Correlation Analysis

Relativity						
	Economic cost of living	Comfortable climate	Physical and mental health	Escape	Destination image	Motivation
Economic cost of living	1					
Comfortable climate	.321**	1				
Physical and mental health	.262**	.592**	1			
Escape	0.099	0.183	.238*	1		
Destination image	.196*	0.162	0.135	0.162	1	
Motivation	.609**	.741**	.761**	.603**	.243*	1
Note: ** indicates $P < 0.01$, * indicates $P < 0.05$						

The correlation analysis revealed a significant positive relationship between all the aforementioned dimensions (economic cost, escape, physical and mental health, and comfort climate) and the feedback of destination information, as well as the motivations for migration. This suggests that retirees who are more motivated to migrate are likely to place a higher value on factors such as the affordability of living costs, the need to escape certain conditions in their home, the importance of maintaining or improving their physical and mental health, and the desire for a comfortable climate. Furthermore, the feedback of destination information, which could include sources such as personal experiences, online reviews, or word-of-mouth recommendations, also plays a role in shaping their motivations.

4.6 Regression Analysis

However, despite these positive correlations, the results of the linear regression analysis showed that the influence of these dimensions on the willingness of retired immigrants to migrate was not statistically significant. In other words, while there is a positive relationship between these factors and the motivation to relocate, the extent to which these factors directly influence the final decision-making process was not substantial enough to reach significance in the regression model. This indicates that while economic cost, escape, health considerations, and climate are all important motivational factors, other variables—potentially including personal preferences, social networks, or external circumstances—may also play a significant role in shaping retirees' migration decisions. This requires further consideration and investigation in follow-up studies.

Figure 8: Regression Analysis

Model	Non-standardize d coefficients		Standard coefficient	T	conspicuousness	VIF
	B	Standard error	β			
(constant)	2.279	0.355		6.417	0.001	
economic cost of living	0.178	0.056	0.273	3.207	0.002	0.888
comfortable climate	0.143	0.074	0.195	1.916	0.058	0.619
physical and mental health	0.105	0.065	0.163	1.615	0.109	0.627
Escape	0.155	0.047	0.273	3.299	0.001	0.940
R ²			0.364			
F			14.175			
P			< 0.001			
Dependent variables: a willingness scale						

4.7 Difference Analysis

Figure 9: Difference Analysis

Sex difference	Male	Female	T	P
Economic cost of living	4.83±1.62	4.22±1.67	1.309	0.854
Comfortable climate	4.37±1.49	4.85±1.49	– 1.169	0.553
Physical and mental health	4.43±1.70	4.63±1.71	– 0.410	0.676
Escape	4.00±1.99	4.02±1.91	– 0.42	0.909
Motivation	4.40±1.20	4.43±1.14	– 0.76	0.660

Age differences	50—55	56—60	61—65	66—70	More than 70	F	P
Economic cost of living	4.44±1.85	4.13±1.20	4.05±1.86	4.50±0.87	4.00±1.04	0.278	0.892
Comfortable climate	4.80±1.59	4.61±1.61	4.68±1.15	5.83±0.58	4.79±1.07	0.443	0.777
Physical and mental health	4.64±1.85	4.34±1.53	4.68±1.57	5.00±1.73	4.64±1.28	0.163	0.958
Escape	4.21±2.06	3.58±1.63	3.32±1.55	3.83±0.29	4.64±1.99	0.970	0.428
Motivation	4.52±1.27	4.16±1.04	4.18±0.88	4.79±0.72	4.52±0.67	0.567	0.687

Provincial differences	Three provinces in the northeast of China	Hong Kong, Macao and Taiwan	Guangdong Province	Other provinces	F	P
Economic cost of living	4.24±1.80	7.00±0	4.65±1.06	4.27±1.67	1.049	0.374
Comfortable climate	4.88±1.40	7.00±0	4.50±1.89	4.59±1.56	1.097	0.354
Physical and mental health	4.89±1.59	7.00±0	4.85±1.51	3.75±1.77	4.008	0.010
Escape	4.03±1.92	7.00±0	4.50±1.80	3.71±1.93	1.262	0.291
Motivation	4.50±1.16	7.00±0	4.63±1.02	4.08±1.03	2.905	0.038

By comparing the differences between different types of retired immigrants, it is found that there are no significant differences in motivation between different age, different residence and different gender, which means that age, residence and gender factors have no influence on the motivation of immigrants. This tells us that we should not consider demographic variables as control variables when conducting subsequent related studies.

5. Conclusion

5.1 Summary

This paper obtains some meaningful knots through an empirical investigation of the motivation of retired immigrants.

First, using exploratory factor analysis to determine the thrust and pull factor of retired immigrants' willingness to travel. Thrust includes the "motivation" factor, and pull force includes the "destination information" factor.

Second, retired immigrants' travel intentions and destination information are influenced by motivational factors, but the effect on travel intentions is insignificant, while the effect on destination information is very significant, with push factors being more significant than pull factors. This suggests that the influence of destination information depends mainly on push factors. Therefore, tourism destination managers should pay special attention to migrants' motivation to visit and further improve the positioning and construction of related urban environments. At the same time, despite the insignificant association, destination managers should pay attention to the impact of motivations on the willingness of retired migrants to travel and consider how to improve promotional and targeting measures to attract migrants.

Third, after combing the relevant literature, it is put forward the idea that the push-pull factor has a direct and positive effect on the tourism willingness, and there is a correlation between the thrust and the pull factor. Through the SPSS analysis factor test, the three research hypotheses are valid. Among them, the correlation between "motivation" and "destination information" in the thrust and pull dimension is high, and the path coefficient is 0.243. Secondly, the correlation between the factors of the thrust dimension is also demonstrated.

Fourth, the most affected tourism motivation is physical and mental health, followed by comfortable climate and economic cost of living. Retired immigrants are more motivated to remain physically and mentally healthy, and want to enjoy a comfortable climate and a more economical cost of living.

Fifth, although this paper has made some progress in the research on the influencing factors of retirement immigrant motivation and travel willingness, there are still deficiencies and the influencing factors need to be further increased.

5.2 Forecast

At present, many southern cities in China have consciously or unconsciously become the moving places of retired immigrants. Some cities have actively helped retired immigrants integrate into the local society by transforming urban facilities and services (Wu & Xu, 2018)^[14]. Some cities have chosen to avoid the issue of retired immigration in hopes of seeking more young people, Not the elderly. More cities adopt the same policies as the ordinary migrants to deal with retired migrants. The natural growth of retired immigrants in some cities in China has begun to take shape. Under the influence of the aging trend, the scale of retired immigrants will only grow, and cities should take a more positive attitude to receive and attract retired immigrants rather than ignore and refuse. We hope that our research can cope with the immigration of retired immigrants and help build tourist destination city and a good relationship between retired immigrants, help some retired immigrants in southern China destination to take a more active attitude to adapt to the arrival of retired immigrants, establish a adapt to the low economic cost of living, high Medical level, high happiness of the living environment. This study provides the empirical foundation for large-scale studies. Although the research data are partly flawed, they can help in the future research direction.

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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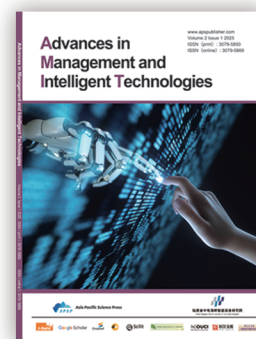
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