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Research on the Configuration Path of Digital Transformation of Specialized, Sophisticated, Distinctive and Innovative Enterprises: An fsQCA Analysis Based on the TOE Framework

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Abstract: It is imperative for Specialized, Sophisticated, Distinctive and Innovative Enterprises to accelerate their digital transformation, as this is a fundamental requirement to break through technical "bottlenecks" and secure a leading competitive advantage. From the perspective of TOE theory framework, this paper adopts the fuzzy-set qualitative comparative analysis(fsQCA) method, selecting 27 listed Specialized and Innovative Enterprises in Guangzhou as the research sample to explore the configurationa adaptation paths of their digital transformation. It is found that there is no single antecedent factor that constitutes a necessary condition for the digital transformation of specialized and special enterprises, but there are three configuration paths that drive their high digital transformation, namely, "technology-led-policy support", "market-led-scale empowerment", and "multi-dimensional collaboration-environmental support"; However, the non-high digital transformation is restricted by two configuration paths: "double shortage of technology-weak policy support", "weak organization-poor market adaptation". Among them, R&D investment at the technical level and antecedent conditions of human capital at the organizational level are particularly important, which are the key supporting elements for the high digital transformation of specialized and innovative enterprises. This paper enriches the related research on digital transformation of specialized and innovative enterprises, and provides a reference for formulating the adaptation path of digital transformation of specialized and innovative enterprises.

Keywords: Specialized; Sophisticated; Distinctive and Innovative Enterprises; Digital Transformation; TOE Theoretical Framework; Configuration Research

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1.Introduction

The Central Economic Work Conference in 2024 clearly pointed out that it is necessary to "strengthen the guidance of scientific and technological innovation, accelerate the digital transformation of specialized and new enterprises, and break through the' neck-stuck "technical bottleneck". According to the data released by the Ministry of Industry and Information Technology, by the end of 2024, the number of specialized and innovative "Little Giant" enterprises in China had exceeded 12,000, of which over 85% were concentrated in the core fields of manufacturing. "Specialization and novelty" is a multi-dimensional and complex concept, which generally refers to those enterprises with a high technical level, strong innovation ability, and strong market competitiveness, and has the characteristics of specialization, refinement, and novelty. It is the main force to solve the current "stuck neck" technical problems and promote independent innovation in the industrial chain and supply chain. Theory and practice show that digital transformation is the reconstruction of value creation mode driven by digital technology, which helps to reshape the value creation of specialized and special new enterprises, and is an inevitable choice for specialized and special new enterprises to break through key core technical barriers and enhance core competitiveness (Lei & Tan, 2021; Qi & Xiao, 2020). Most of the existing specialized and innovative enterprises are still in the primary stage of digital transformation, and their in-depth application is insufficient. The main reason is that compared with large enterprises, specialized and innovative enterprises have the characteristics of small scale and weak ability to obtain external resources, and their digital transformation also presents the prominent contradiction of "strong willingness to transform but weak ability" and "urgent demand but vague adaptation path" (Yu et al., 2023). Therefore, it is of great theoretical and practical value to guide specialized and innovative enterprises to accelerate digital transformation.

The existing research focuses on the digital transformation of specialized and innovative enterprises. Based on the resource-based view, some scholars believe that unique resources such as R&D investment, technical capability, and digital talent reserve, which are difficult to replace and replicate, are the core driving factors of digital transformation (Qi et al., 2023; Mao & Dun, 2023; Zhang et al., 2022). From the perspective of dynamic capability theory, some scholars pointed out that when enterprises cope with changes in internal and external innovation environment, the abilities of environmental perception, learning absorption, integration and reconstruction are the driving force for enterprises to cope with changes in internal and external innovation environment, integrate and utilize internal and external resources, and realize digital transformation (Cao et al., 2024; Ma et al., 2022); Another study emphasizes that policy support and market-oriented environment can provide strong external empowerment for digital transformation from the perspective of institutional theory (Zhou et al., 2025; Wang , 2024). The existing literature research on the digital transformation of specialized and innovative enterprises provides theoretical support for the development of this study, but the existing research has two limitations: First, it focuses on the "net effect" analysis of a single factor, ignoring the interaction of multi-dimensional factors of technology, organization and environment; Second, there is a lack of targeted discussion on regional heterogeneity and industry differences, which makes it difficult to form a replicable transformation path for regions and industries.

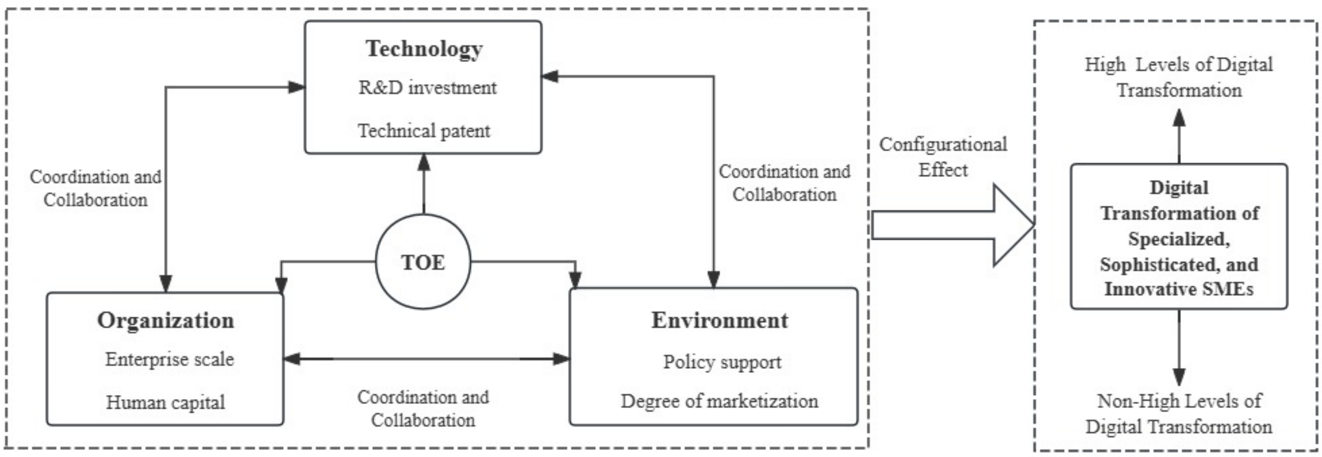
The TOE framework (technology-organization-environment) provides theoretical support for solving this dilemma. This framework integrates influencing factors from internal and external dimensions of enterprises, and is suitable for analyzing the transformation mechanism in complex situations. Therefore, starting from the TOE theoretical framework, this paper adopts the fuzzy set qualitative comparative analysis (fsQCA) method, takes 27 specialized and innovative listed enterprises in Guangzhou as research samples, and deconstructs the question: What are the core influencing factors of digital transformation of specialized and innovative enterprises? How do multiple factors drive digital transformation through the configuration effect? This paper reveals the nonlinear mechanism of "multiple causes and one effect" in digital transformation, in order to provide theoretical and practical reference for the differentiated transformation path of specialized and innovative enterprises.

2.Theoretical framework

The TOE theoretical framework, based on technology-organization-environment, was put forward by researchers Tornatzky and Fleischer in 1990. It is mainly suitable for attribution analysis of enterprise or organization behavior decisions in different situations, and is essentially a comprehensive analysis framework based on technology application situations (Qiu, 2017). Combined with the characteristics of "small but specialized, small but refined" of specialized and innovative enterprises, the antecedent conditions are screened based on three levels of technology, organization, and environment, and the analysis framework of digital transformation of specialized and innovative enterprises is constructed from the perspective of configuration (as shown in Figure 1).

First, the technical level. The most typical feature of the technical level of specialized and innovative enterprises is "novelty", that is, technological innovation, which directly determines the R&D and innovation potential of digital technology of enterprises. The essence of digital transformation is the deep integration of digital technology and business processes, which requires continuous R&D investment at the front end and sufficient technical patent reserves at the back end. (1) From the front end, on the one hand, high R&D investment can accelerate the digital technology reserve of enterprises (such as industrial software development, digital platform construction, smart device upgrade, etc.) and provide technical support for the digital transformation of enterprises (Wu et al., 2021); On the other hand, R&D investment intensity reflects enterprises' acceptance of digital transformation, and enterprises with higher innovation investment can attract digital technical talents to join, forming a positive cycle of "investment-technology-talents" (Zhao et al., 2021). (2) From the back end, a technology patent is a scarce, exclusive, and economically valuable resource, which is the direct embodiment of the digital technology innovation ability of enterprises and the core asset of digital transformation. On the one hand, the more technology patents an enterprise has, the stronger its autonomy and controllability in the market, thus reducing its dependence on external technology supply (Qi et al., 2023); On the other hand, the accumulation of technology patents can enhance the bargaining power and market competitiveness of enterprises (Ano & Bent, 2022; Wang, 2024).

Figure 1 Theoretical Model



Second, the organizational level. The structural characteristics and resource base of an organization profoundly affect the digital transformation and development of enterprises (Mi, 2019). The organizational level is the internal guarantee for the digital transformation of specialized and innovative enterprises, which determines the absorptive capacity of enterprises to digital technology, the efficiency of resource integration, and the adaptability of management. Digital transformation is not only a technological change, but also a systematic reconstruction of enterprise organizational structure and management mode, which needs to be supported by appropriate organizational scale and sufficient human capital (Chirico & Nordqvist, 2010). (1) Enterprise scale reflects the resource reserve capacity and risk-taking level of specialized and innovative enterprises, and has a "double-edged sword" effect on digital transformation. On the one hand, a large enterprise scale can provide sufficient funds, equipment, and talent reserves for digital transformation (Wu et al., 2021); On the other hand, the organizational structure of large-scale enterprises is relatively complex, which may lead to inefficient transformation decision-making, increased transformation costs, and even hinder the digital transformation of enterprises. Although the smaller enterprise scale may limit the enterprise's resource acquisition and market share ability, for specialized and innovative enterprises, their "specialized and refined" characteristics make their business more focused and easier to play the role of scale advantage (Wu & Shi, 2022). (2) Human capital is the core subject of the digital transformation of specialized and innovative enterprises, which directly determines the efficiency and effectiveness of digital transformation. On the one hand, the high level of human capital can enable enterprises to learn efficiently, absorb digital technology knowledge and transform rapidly, thus accelerating the process of digital transformation of enterprises; On the other hand, the high level of human capital can accelerate the change of organizational culture, enhance the employees' sense of identity with digital transformation, and thus reduce the obstacles to digital transformation (Ano & Bent, 2022).

Third, the environmental level. Enterprise digital transformation is closely related to its dynamic environment, which determines the institutional environment, market demand, and resource acquisition of enterprise digital transformation. Because of its characteristics of "small but specialized, specialized and refined", the digital transformation of specialized and innovative enterprises needs to be highly dependent on the support of the external environment (Jia et al., 2024). (1) Policy support is an important "catalyst" for the digital transformation of specialized and new enterprises, which can reduce the transformation cost and ease the financing constraints. The government adopts policies such as financial subsidies, tax incentives, and special support. On the one hand, digital transformation requires a large amount of capital resources. The government provides direct financial support or indirect incentives for digital transformation of enterprises through policy support such as financial subsidies, tax incentives and steering support, thus reducing the costs and risks of transformation (Boeing, 2016); On the other hand, policy support has a "signal effect", which can attract financial institutions and other third parties to cooperate with enterprises, ease the financing constraints of enterprises, ease the financial difficulties of digital transformation, and form a collaborative empowerment of "policy-capital-technology" (Zhang et al., 2021). (2) The degree of marketization reflects the development level of market economy, the intensity of market competition, the circulation speed of products and elements, and the perfection of the system, which affects the decision-making of digital transformation of enterprises to a certain extent. First, a higher degree of marketization means that the market environment is more competitive, and it is easier for enterprises to promote digital transformation to gain market competitive advantage; Second, the improvement of marketization will enhance the liquidity of factor resources, attract digital talents, capital and other resources to gather, improve the efficiency of external resource allocation of enterprises, and provide sufficient resource support for the digital transformation of enterprises; Third, the high degree of marketization usually has a more perfect institutional environment, and the systems of intellectual property protection and data security supervision are more perfect, thus reducing the institutional risks faced by enterprises in digital transformation (Wang et al., 2023).

3.Research design

3.1 Research Methodology

As a key strategic choice for the innovation and development of specialized and innovative enterprises, the realization process of digital transformation is not a linear result driven by a single factor, but a complex process influenced by multi-dimensional factors such as technical capability, organizational strategy, and external environment. Because traditional econometric research methods (such as regression analysis, structural equation model, etc.) only focus on analyzing the "net effect" of a single variable, it is difficult to reveal the "combination effect" formed by the interaction of multiple factors. Qualitative comparative analysis (QCA) is based on set theory, focusing on the combination of antecedent conditions, and paying attention to the complex causal relationship between antecedent condition configuration and result variables, which is more suitable for the research content and goal of this paper. Therefore, this paper chooses the past set qualitative comparative analysis (fsQCA) to explore how to dynamically match the configuration effect path of digital transformation of specialized and innovative enterprises from the perspective of TOE theory.

3.2 Sample data

This paper strictly follows the principle of "representativeness, availability, and continuity" of data, and selects Guangzhou specialized and innovative listed enterprises as research samples. The sample screening process and standards are as follows: (1) Based on the list of specialized and special new enterprises published by Guangzhou Industry and Information Technology Bureau, combined with Wind database, "specialized and special new" listed enterprise label screening; (2) Excluding ST/*ST enterprises and enterprises with data missing rate exceeding 20%; (3) Enterprises whose main business is traditional service industry (such as catering and retail) are excluded, so the digital transformation characteristics of such enterprises are atypical. Finally, 27 sample enterprises were determined, covering 162 observed values.

3.3 Variable Definition and Calibration

3.3.1 Result variables

Digital transformation (DT): Drawing lessons from the measurement methods of digital transformation such as Wu Fei et al. (2021) and Zhao Yuyu et al. (2021), the annual report data of 27 specialized and special listed companies in Guangzhou from 2019 to 2024 were obtained through Wind database and CSMAR database, and Python text mining technology was used to crawl the keywords such as "digital", "intelligent", "big data" and "cloud computing" in the annual report.

3.3.2 Antecedent variables

R&D investment (RD): measured by the proportion of R&D expenditure to operating income;
Number of patents (PA): Measured by the sum of the number of technical inventions, utility model patents, and design patents owned by enterprises;
Enterprise Scale (SC): Measured by the total assets of the enterprise;
Human Capital (HC): Measured by the proportion of technical personnel in the total number of employees;
Policy support (PO): Measured by whether the enterprise has won national, provincial, municipal, district, and county awards or financial support, the value of "Yes" is 1, and the value of "No" is 0.
Marketization degree (MA): The marketization degree of the region where the enterprise is located is measured by using the marketization index of China's provinces compiled by Wang et al. (2023), and the data is calculated by using the marketization index value of Guangdong Province in the corresponding year.
Combined with the measurement methods of the above result variables and antecedent variables, as well as the data collation of sample enterprises, the definitions of each variable and descriptive statistical analysis results are shown in Table 1.

Table 1 Definition and descriptive statistical analysis of variables

Variable type	Variable name	symbol	Measurement standard	Descriptive statistics				
				N	Mean	Sd	Max	Min
Result variable	Digital transformation	DT	The key dictionary is constructed by text mining method, and the index is calculated by entropy method	162	3.412	1.287	6.925	0.987
Antecedent variable	R&D investment	RD	R&D expenditure/operating income (%)	162	7.563	2.587	12.876	1.987
	Technical patent	PT	Total number of technical inventions, utility models or software works and other proprietary technologies (pieces)	162	4.621	2.015	9.987	1.324
	Enterprise scale	SC	Total assets at the end of the year (10,000 yuan)	162	23.015	1.567	26.892	20.345
	Human capital	HC	Number of technicians/total employees	162	23.876	9.567	48.234	5.987
	Policy support	PO	Whether it has won national, provincial, district and county awards or financial support; Obtained = 1, not obtained=0	162	0.667	0.472	1	0
	Degree of marketization	MA	Drawing lessons from the marketization index of China's provinces compiled by Wang et al.(2023) and others to measure the degree of marketization in the region where enterprises are located	162	12.015	0.623	13.124	10.987

3.Variable calibration

According to the data and conditions of the result variable and the antecedent variable, the direct calibration method is used to assign all the variable data to the membership score of the fuzzy set. Among them, the anchor points (critical values) used for digital transformation, R&D investment, technology patents, enterprise scale, human capital and market environment calibration are set to 75% quantile (full membership, membership = 1), 50% quantile (intersection, membership ≈ 0. 5) and 25% quantile (completely non-membership, membership = 0) For the policy support variable (PO), assign "1" directly to the supported samples, and set "0" to the unsupported samples. In order to avoid the situation where the membership degree is just 0.5, this paper adopts the method of adding 0.001 to the observation samples whose membership degree is less than 1. After calibrating according to the above method, the membership degree of all variables meets the requirements of a fuzzy set (the value range is 0-1), and the specific calibration results of anchor points are shown in Table 2.

Table 2 Variable calibration results

Variable name	symbol	Complete subordination (75% quantile)	Crossing point (50% quantile)	Completely non-subordinate (25% quantile)	Calibration basis
Digital transformation	DT	4.325	3.385	2.215	Sample quantile
R&D investment	RD	9.234	7.452	5.312	Sample quantile
Technical patent	PT	6.123	4.563	2.987	Sample quantile
Enterprise scale	SC	24.567	22.987	21.654	Sample quantile
Human capital	HC	31.234	22.654	14.892	Sample quantile
Policy support	PO	1	0.5	0	Direct calibration of dummy variables
Degree of marketization	MA	12.789	12.003	11.456	Sample quantile

4.Empirical analysis

4.1 Necessity analysis of a single conditional variable

In the QCA method, if a single condition that causes the result to occur always exists, it is called a necessary condition of the result. Necessity analysis aims to test whether a certain antecedent variable constitutes a necessary prerequisite for the result variable (high digital transformation or non-high digital transformation), which is usually measured by whether the Consistency level is greater than 0.9. If the consistency threshold of the condition variable is greater than 0.9, it means that the necessary condition exists. In this paper, the fsQCA3.0 software is used to analyze the necessary conditions for the digital transformation of Guangzhou 27 “specialized and innovative” listed enterprises. The results show that (as shown in Table 3): the necessity consistency level of all antecedents is lower than 0.9, which indicates that no single antecedent condition in this paper constitutes a necessary condition for digital transformation, thus verifying that digital transformation needs multi-condition coordination rather than “complex configuration characteristics” driven by a single antecedent condition.

Through the results in Table 3, it can be found that the consistency of R&D investment is the highest (0.803), followed by human capital (0.786) and policy support (0.754), indicating that enterprises with high R&D investment, high human capital and policy support are easier to achieve high digital transformation; The consistency of technology patent (0.712) and marketization degree (0.698) is the second, and the consistency of enterprise scale (0.635) is the lowest. From the necessity of non-high digital transformation, ~ R&D investment (0.785) and ~ human capital (0.762) have the highest consistency, indicating that enterprises lacking R&D investment or human capital are more likely to fall into non-high transformation, and they are the “key bottlenecks” of transformation; The consistency of ~ policy support (0.731) and ~ technology patent (0.705) is second, which further verifies the core role of technology and policy.

Table 3 Necessity analysis results of a single condition

Antecedent condition	High digital transformation		Non-high digital transformation	
	Consistency	Coverage	Consistency	Coverage
R&D investment (RD)	0.803	0.832	0.235	0.256
~ R&D investment	0.246	0.268	0.785	0.807
Technical Patent (PT)	0.712	0.735	0.321	0.343
~ Technical patent	0.334	0.356	0.705	0.728
Enterprise size (SC)	0.635	0.658	0.402	0.425
~ Enterprise size	0.415	0.438	0.632	0.655
Human Capital (HC)	0.786	0.809	0.254	0.277
~ Human capital	0.267	0.29	0.762	0.785
Policy Support (PO)	0.754	0.777	0.289	0.312
~ Policy support	0.302	0.325	0.731	0.754
Marketization degree (MA)	0.698	0.721	0.335	0.358
~ Degree of marketization	0.348	0.371	0.678	0.7

4.2 Sufficiency Analysis of Conditional Configuration

In order to effectively identify the effective conditional configurations that lead to “high digital transition” or “non-high digital transition”, this paper draws lessons from Rihoux and Ragin’s research, and sets the consistency threshold to 0.8 (to ensure configuration reliability), PRI consistency to 0.8 (to avoid false configuration), and acceptable case frequency to 3 (considering the number and scale of samples). Simple solution, intermediate solution, and complex solution will be produced in the analysis process, and the combination of conditions of complex solutions may lead to too many solutions and the risk of over-fitting, thus reducing the external validity of the research results. Therefore, this paper follows the principle of “intermediate solution as the mainstay, simple solution as the supplement”, identifies the core conditions and marginal conditions of digital transformation of Guangzhou specialized and new enterprises, and obtains the final path.

4.2.1 Analysis of high digital transformation results

It can be seen from Table 4 that there are three configurations for Guangzhou specialized and special listed enterprises to realize high digital transformation, and the consistency levels of high digital transformation configurations are 0.935, 0.918 and 0.896 respectively, and the overall consistency of the three configurations is 0.912, which is greater than the consistency threshold of 0.8, indicating that all three configurations are sufficient conditions for specialized and special listed enterprises to realize high digital transformation. In addition, the coverage of the three configurations are 0.258, 0.243 and 0.231 respectively, indicating that the three configurations can explain 25.8%, 24.3% and 23.1% of the high digital transformation of specialized and special enterprises respectively; At the same time, the coverage of the solutions of the three configurations is 0.732, which indicates that the conditional configuration has a good explanatory power for the cases of specialized and new listed enterprises. According to the different core and edge conditions, this paper further summarizes the three high-digital transformation configurations into three paths:

1. Technology-led-policy-supported driving path

In Configuration 1, two antecedent conditions (R&D investment and technology patent) exist at the core, which shows that high R&D investment and more technology patents play a core role; Policy support exists as marginal conditions, and the degree of marketization at the environmental level and the scale and quality of human capital at the organizational level can be flexibly adjusted, which highlights the important influence of technology leadership and policy support on the digital transformation of specialized and innovative enterprises. Configuration 1 path has the highest consistency, which is mainly suitable for technology-intensive enterprises (such as electronics and semiconductors, high-end equipment manufacturing, etc.). The core logic formed by the configuration 1 path is to accelerate the accumulation of digital technology reserves for technology investment, and policy support significantly reduces the cost of trial and error in transformation. A typical case of this kind of path is Ruike Laser. By developing the “Digital Production System of Fiber Laser”, the production efficiency is improved and the digital transformation is promoted.

2. Market Leading-Driving Path of Scale Empowerment

In Configuration 2, the core conditions of organization level (enterprise scale, human capital) and marketization degree exist, which shows that large enterprise scale, more human capital, and high marketization degree play a core role; the Technical level (R&D investment and technology patent) and policy support conditions may be missing. This kind of path is generally suitable for enterprises with large scale and sufficient human capital (such as electronic information and intelligent manufacturing). The core logic of its formation is that the advantages of large enterprise scale can provide basic resources for enterprises to transform, more human capital can provide a guarantee for enterprises’ technology application ability, and a high degree of marketization can create a demand factor environment for enterprises. A typical case of this kind of path is Vision Electronics. Relying on Guangzhou’s high market environment, it has built a “digital R&D platform for intelligent interactive equipment”, integrating upstream and downstream supplier data and shortening the R&D cycle.

3. Driving Path of Multi-dimensional Collaboration-Environment Support

In Configuration 3, the core conditions of environmental level (policy support and marketization degree) exist, which shows that good policy support and high marketization degree play a central role; R&D investment and enterprise scale exist as marginal conditions, and technology patents and human capital can be flexibly adjusted, which shows the multi-dimensional synergy among technology, organization, and environment. This kind of path is generally suitable for enterprises with medium resources but a superior external environment (such as biomedicine and intelligent equipment). The logic of its formation provides internal support for enterprises for technology research and development and manpower scale, while policy support and market environment create external double thrust for enterprises. A typical case of this kind of path is Tongda Electric, which drives the digital transformation of the bus electrical system through "policy subsidy + market demand" and reduces the equipment failure rate.

Table 4 Sufficiency analysis results of condition configuration for digital transformation of "specialized and innovative" listed enterprises

Variable name	High digital transformation			Non-high digital transformation	
	Configuration 1	Configuration 2	Configuration 3	Configuration 4	Configuration 5
R&D investment (RD)	●	-	○	U	-
Technical Patent (PT)	●	-	-	U	-
Enterprise size (SC)	-	●	○	-	U
Human Capital (HC)	-	●	-	-	U
Policy Support (PO)	○	-	●	※	-
Marketization degree (MA)	-	●	●	-	※
Consistency	0.935	0.918	0.896	0.928	0.905
PRI consistency	0.889	0.867	0.853	0.876	0.862
Coverage	0.258	0.243	0.231	0.352	0.393
Unique coverage	0.097	0.085	0.082	0.123	0.138
Inter-group consistency adjustment distance	0.145	0.148	0.132	0.112	0.105
Overall PRI	0.868			0.869	
Consistency of global solutions	0.912			0.921	
Coverage degree of global solution	0.732			0.745	

Note: "●" indicates the existence of core conditions, and "U" indicates the absence of core conditions; "○" indicates the existence of edge conditions, and "※" indicates the absence of edge conditions; "-" indicates that the condition variable may exist or be missing; "Empty" means that the condition is unconstrained.

4.3.2 Configuration analysis of non-high digital transformation

The adequacy analysis of non-high digital transformation aims to identify the combination of core conditions that hinder the realization of digital transformation. Table 4 shows that there are two configurations of non-high digital transformation; the consistency levels of the two configurations are 0.928 and 0.905, respectively, and the overall consistency of the two configurations is 0.869, which is greater than the consistency threshold of 0.8. At the same time, the overall solution coverage of the two configurations is 0.745, which means that these two configurations have strong explanatory power and relatively high reliability. It is worth noting that in Configuration 4 of non-high digital transformation, R&D investment and technology patent core are missing, and policy support is marginally missing, which shows that technical and policy support are the basic threshold for realizing high digital transformation in the antecedent conditions of digital transformation of specialized and special family enterprises. If they are missing at the same time, the digital transformation will directly fall into a stagnation state; In Configuration 5, small enterprise scale, small human capital and low degree of marketization are another configuration path that hinders the realization of high digital transformation, mainly because the scale ability of the organization and a good market environment are the guarantee conditions for the realization of high digital transformation, and if they are weak at the same time, they will lead to the “powerlessness” of digital transformation.

5.Conclusion and enlightenment

5.1 Research conclusions

Based on the TOE theoretical framework, this paper deconstructs multiple concurrent factors and configuration paths affecting the digital transformation of specialized and innovative enterprises by the fsQCA method, taking 27 specialized and innovative listed enterprises in Guangzhou as research samples. The main conclusions are as follows:

(1) There are three ways to drive the high-digital transformation of specialized and innovative enterprises, namely, “technology-led-policy support”, “market-led-scale empowerment”, and “multi-dimensional collaboration-environment support”, which are respectively adapted to specialized and innovative enterprises with technology-intensive, scale human capital, and environment adaptation, reflecting the digital high-digital transformation characteristics of “all roads lead to the same goal”.

(2) Non-high digital transformation is mainly divided into two configuration paths: “double shortage of technology-weak policy support” and “weak organization-poor market adaptation”. The former reflects the “lack of basic threshold” of technology and policy, while the latter reflects the “insufficient implementation guarantee” of organization and market.

(3) The factor of digital transformation of specialized and innovative enterprises is the result of multi-factor conditions. No single condition can realize the high digital transformation of specialized and innovative enterprises. The R&D investment at the technical level and the antecedent conditions of human capital quality at the organizational level are particularly important. If they are lacking or weak, the enterprises will easily fall into the bottleneck of transformation.

(4) The digital transformation configuration path of specialized and innovative enterprises reflects the heterogeneity of industries, and different industry characteristics realize the digital transformation configuration path. For example, the electronic information industry prefers the path of “market leading-scale empowerment”, the high-end equipment manufacturing industry relies on the path of “technology leading-policy support”, and the biomedical industry needs “multi-dimensional collaboration-environmental support”.

5.2 Research Enlightenment

1. Theoretical contribution

(1) Combining with the characteristics of “small but specialized, small but refined” of specialized and innovative enterprises, the measurement of TOE dimensions is refined, and the “asymmetric configuration effect” is identified, enriching the application of the TOE framework in the digital field of specialized and innovative enterprises. (2) The fsQCA method captures the nonlinear relationship of “multiple causes and multiple effects” and “one cause and multiple effects”, identifies three equivalent paths and two obstacle configurations, makes up for the limitation of “linear hypothesis” in traditional regression analysis, and provides a new perspective for the study of causal mechanisms of digital transformation.

2. Practical enlightenment

(1) At the enterprise level, all kinds of enterprises should establish the concept of digital transformation and innovation, combine the unique and precise positioning of the industry, and avoid the shortcomings of factors. For example, technology-intensive enterprises (such as Ruike Laser and Gaoyun Semiconductor) should focus on the path of “technology-led-policy support”, increase investment in research and development, strengthen patent layout, and actively declare digital special policies to reduce transformation costs; Large-scale human capital enterprises (such as Vision Electronics and Yuncong Technology) should rely on the path of “market-led-scale empowerment”, integrate upstream and downstream digital resources through scale advantages, increase the proportion of R&D technicians, and use Guangzhou’s high market-oriented environment to meet customer needs and accelerate digital landing; Medium-sized enterprises with resources (such as Tongda Electric and Anbiping): adopt the path of “multi-dimensional collaboration-environmental adaptation”, rely on Guangdong-Hong Kong-Macao Greater Bay Area digital factor market to strive for policy support, and at the same time maintain basic

R&D investment and moderate scale expansion to make up for the shortcomings of single factor. (2) At the government level, the government should improve the differentiated and targeted policy supply support system and implement classified policies. For example, for the electronic information industry, financial subsidies for "digital scale subsidies" can be introduced; For the high-end equipment manufacturing industry, set up tax incentives for "special technology research and development"; For the biomedical industry, provide financial support of "multi-dimensional collaborative support". (3) At the regional level, with the help of Guangdong-Hong Kong-Macao Greater Bay Area's policy advantage of "digital factor market integration", Guangzhou sample enterprises will be promoted to cooperate with digital technology enterprises in Shenzhen and Dongguan (such as Huawei and DJ), share industrial Internet platforms and digital talent resources, build a "digital transformation benchmark" enterprise, sum up replicable experiences and promote them among specialized and new enterprises in the city, and form a transformation pattern of "benchmark-overall improvement".

3. Research deficiency and prospect

There are still the following shortcomings in this study: (1) The sample only covers 27 specialized and special newly listed enterprises in Guangzhou, and does not include unlisted specialized and special new enterprises. In the future, it can be expanded to specialized and special new enterprises in Guangdong-Hong Kong-Macao Greater Bay Area to enhance the universality of conclusions; (2) The antecedent conditions do not include organizational governance variables such as "ownership structure" and "intergenerational inheritance", which can be introduced in the future to enrich the condition system; (3) Without in-depth analysis of the dynamic evolution of the path (such as path changes in different years), the time series fsQCA method can be used to explore the temporal heterogeneity of the transition path in the future.

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Conflict of Interests

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

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