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Configurations of Green Total Factor Productivity Improvement Conditions in the Yangtze River Delta Urban Agglomeration: based on fsQCA

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Abstract

Green total factor productivity (GTFP) is an important criterion for evaluating high-quality economic development. The factors that affect GTFP are diverse and complex. Traditional linear analysis methods are not suitable for analyzing complex systems. This article is based on complex economics and takes 27 cities in the Yangtze River Delta urban agglomeration as the research object. Through a configuration perspective and QCA method, it studies the complex driving mechanisms that affect GTFP. Research has found that a single effective government and effective market conditions are not necessary conditions for generating high GTFP, but require a high degree of synergy between the government and the effective market. This is mainly reflected in the creation of a digital economy environment, optimization of the business environment, attracting continuous investment in factors, activating the innovation drive and vitality of market entities, promoting industrial upgrading and digital transformation, and ultimately improving GTFP. This study also reveals the configuration that generates non high GTFP. Compared with high GTFP, there is a strong causal asymmetry. This highlights the complexity of factors affecting GTFP and is also conducive to proposing targeted recommendations.

Keywords

Yangtze River Delta Urban Agglomeration; Green Total Factor Productivity; fsQCA.

1. Introduction

The coordinated development of environment and economy, the enhancement of Green Total Factor Productivity (GTFP), and the promotion of green development have become hot research topics. The factors that affect GTFP are diverse, including technological progress, industrial structure, market transaction costs, factor inputs, and business environment. Firstly, the new economic growth theory points out that the driving force of economic efficiency comes from technological progress and technological efficiency[1]. Secondly, development economics believes that the upgrading of industrial structure and input factor structure promotes total factor productivity[2].Thirdly, reducing institutional and market transaction costs can effectively improve the level of total factor productivity[3]. However, some scholars have pointed out that technological progress is a necessary but not sufficient condition for improving total factor productivity and promoting the transformation of economic growth patterns, and the relationship between the two is complex[4]. Traditional linear analysis methods, such as regression analysis, are not suitable for analyzing complex systems. The configuration

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perspective and QCA methodology are suitable for studying the complex driving mechanisms that affect GTFP[5, 6].

Therefore, based on a configuration perspective, this article combines the fuzzy set qualitative comparative analysis method (fsQCA) to analyze the complex causal relationship affecting the regional GTFP level. And based on existing research, answer: What factors are the key conditions for improving regional green total factor productivity? What are the complex driving mechanisms that affect the level of green total factor productivity in a region? How to optimize relevant influencing factors and elements to promote high-quality development of regional economy?

The possible contributions of this article are as follows: Firstly, based on a configuration perspective, systematically analyze the patterns and mechanisms of various factors promoting GTFP, providing new ideas for empirical research on high-quality regional economic development. Secondly, this article analyzes the complex mechanism of the impact of government and effective market synergy on regional GTFP levels, and explores the weak factors that affect the improvement of regional GTFP. Thirdly, guide factors to gather in regional green industries and industries, and assist in the upgrading of traditional industries. To achieve high-quality green development in the region by alleviating factor mismatch, building coordinated regional competitive relationships, and enhancing regional GTFP.

2. Literature References

Green total factor productivity is proposed based on the concept of total factor productivity[7], which is an indicator of the comprehensive productivity of an economy in sustainable development, emphasizing environmental sustainability and resource efficiency levels. At present, research on the influencing factors of GTFP mainly focuses on external and internal factors. External factors refer to factors such as macroeconomic environment and policies. For example, digital economy[8], infrastructure construction, financial development[9], industrial agglomeration, human capital structure[10], environmental regulatory policies[11], external economy[12], financing constraints and institutional environment[13, 14], etc.

Internal factors mainly refer to the characteristics and business strategies of the enterprise itself. This includes the technical level[15], organizational structure, and management capabilities of the enterprise[16]. New technologies can improve resource utilization efficiency, reduce waste and pollution. More efficient resource management methods can reduce resource waste, reduce environmental impact, and improve production efficiency and employee quality. A well-educated workforce is usually better equipped to adapt to new technologies and innovations, thereby improving production efficiency, enhancing awareness of environmental sustainability, and promoting more environmentally friendly behavior and decision-making.

2.1. Factors Affecting GTFP

2.1.1. Digital Economy and GTFP

The relationship between the digital economy and GTFP is based on the development of traditional economic growth theories. In the context of the digital economy, the existing production function structure may change due to the layout of industrial digitization, digital industrialization, and digital innovation. This will activate regional innovation vitality and green innovation capabilities, accelerate industrial structure adjustment, and form new driving forces for economic development, thereby improving green total factor productivity[17-19]. On the other hand, China's digital economy is still in its early stages of development. Old technologies, equipment, organizational structures, business models, and concepts may not be able to adapt to the impact of new technologies on productivity, resulting in a certain degree of "disruptive innovation" effect[20], which is not conducive to improving the efficiency of green

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technologies. Therefore, the direction in which the digital economy affects green total factor productivity is not yet clear.

2.1.2. Business Environment and GTFP

Institutional factors represented by the business environment are an important source of driving TFP growth[21]. The existing literature has empirically discussed the possible mechanisms by which the business environment can enhance total factor productivity, mainly from the aspects of resource allocation efficiency[22], production factor agglomeration[23], endogenous innovation ability[24], promoting marketization process, and promoting legal development[25, 26]. Most studies have confirmed the positive effects of the business environment. Some scholars also believe that government regulation may hinder investment and employment growth, resulting in inefficient resource allocation, thereby reducing productivity and economic growth rate[27]. It can be seen that the relationship between the business environment and green total factor productivity is still worth further research.

2.1.3. Technological Innovation and GTFP

Empirical studies have shown that the driving force behind GTFP growth at the technological level mainly comes from technological progress and scale efficiency growth[28]. Technological innovation drives industrial transformation, optimizes demand structure, and thus has an impact on technological efficiency, technological progress, and green environmental protection, which are the key to achieving GTFP growth[17, 29, 30]. However, inappropriate technological innovation may weaken the intrinsic motivation of technological innovation due to its difficulty in matching with the factor endowment structure[31]. In addition, some scholars have proposed the paradox of technology and environment. If technological innovation is solely aimed at economic growth, it is not conducive to the utilization of limited resources and the development of the ecological environment[32], thereby reducing the level of GTFP.

2.1.4. Inclusive Finance and GTFP

Digital inclusive finance has advantages such as low cost, inclusive flexibility, and green attributes. It optimizes resource allocation, promotes smooth information channels, stimulates energy conservation and green technology innovation, promotes industrial structure transformation and upgrading, promotes environmentally friendly economic activities, and ultimately enhances GTFP[33]. Of course, the impact on GTFP will show different effects at different stages of development and across industries: in the initial stage, the increase in GTFP will be suppressed due to a large amount of capital investment; For capital intensive and technology intensive industries, the output cycle is longer, increasing the cost of environmental pollution control and energy conservation and emission reduction will increase the burden on enterprises in the short term, and to some extent, will also inhibit the growth of GTFP. Of course, with the continuous expansion of the scope of digital inclusive financial services, enterprises can obtain more financial support after improving their green development level. The advantages of funding and technology greatly improve the production efficiency of enterprises, which will then improve GTFP [34].

2.1.5. Changes in Industrial Structure and GTFP

Diversification and upgrading of industrial structure have a significant promoting effect on the improvement of green total factor productivity [35, 36]. As for cities, improving their innovation level and promoting industrial upgrading can indirectly enhance their green total factor productivity[37]. The transformation and interaction of industrial structure determine the way and quality of economic growth. To promote the growth of total factor productivity, attention should be paid to the synchronous optimization and strategic adjustment of the structure between industries and the internal structure of industries, to improve the efficiency of production factor allocation, promote the deep integration and development of the service industry and manufacturing industry, and gradually shift towards bidirectional driving[38]. But

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some scholars have also found that there is a threshold effect of industrial structure change in promoting the improvement of TFP, that is, only when the Internet develops to a certain level, the interaction between industrial structure change and the Internet on total factor productivity changes from negative to positive, and further strengthens when the Internet development level increases [39].

2.1.6. Digital Transformation of Enterprises and GTFP

The shaping of enterprise product competitiveness through digital transformation will be directly reflected in the improvement of enterprise product innovation capability and profit margin. This enables enterprises to expand their market strategic layout and improve operational management efficiency. Ultimately, mechanisms such as promoting green technology innovation, strengthening human resource allocation, optimizing human capital structure, advancing the integration and development of advanced manufacturing and modern service industries, stimulating innovation vitality, and enhancing green innovation capabilities will have a positive impact on the green total factor productivity of manufacturing enterprises[18, 40-42]. Some studies also suggest that promoting digitalization in enterprises can lead to low research and development efficiency [43]. The impact of digitalization on enterprises has a " too much of a good thing" effect, and excessive investment in digitalization may have little effect, even leading to a decline in business performance[44].

In summary, existing research is mainly based on quantitative analysis of causal symmetry. In fact, there is still a lot of room for expansion in the research perspective. The impact mechanism of urban GTFP includes causal complexity issues such as multiple concurrent causal relationships, causal asymmetry, and equivalence of multiple schemes. We must adopt a configuration perspective from a holistic system perspective. Secondly, there is a lack of research on the synergistic mechanisms between macroeconomic environment (such as digital economy), proactive government (such as business environment), and effective markets (such as technological innovation, enterprise digital transformation, digital inclusive finance investment, industrial structure changes, etc.), as well as the linkage effects with the improvement of regional green total factor productivity.

2.2. Theoretical Model: Complex Pathways and Mechanisms to Promote Gtfp from a Configuration Perspective

The factors that affect GTFP are diverse, involving multiple dimensions such as country, industry, and enterprise [45]. Different elements may compete, coexist, and evolve together in terms of goals and behavioral logic. That is to say, the impact mechanism of regional GTFP enhancement includes multiple concurrent causal relationships (digital economy, business environment, technological innovation, enterprise digital transformation, digital inclusive finance investment, industrial structure changes, etc.), causal asymmetry, and multiple equivalent solutions, among other causal complexity issues. A holistic configuration perspective must be adopted, using qualitative comparative analysis (QCA) to treat the research object as a configuration of different combinations of conditional variables. Through set analysis, the relationship between element configuration and results must be discovered, in order to explore the dominant factor configuration that affects regional GTFP. It is necessary to comprehensively consider the synergy between economic environment, industrial structure upgrading, institutions, finance, and technological innovation, in order to fully drive green total factor productivity through technological innovation. The specific research analysis elements and the theoretical model of linkage effects are shown in Figure 1.

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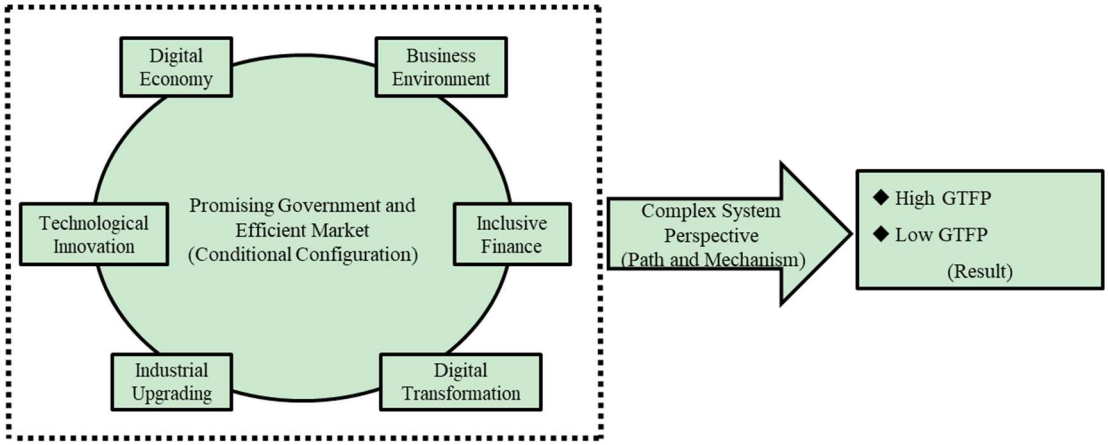

Figure 1. Theoretical model of linkage effect

3. Research Design

3.1. Research Methods

This article adopts the Qualitative Comparative Analysis (QCA) method, which is based on a holistic system view and is also suitable for small sample analysis. It can provide a complete interpretation of the complex multiple concurrent relationships between the influencing conditions involved in the case. The QCA method is not exhaustive and is suitable for analyzing configurations of 4-7 conditions. By analyzing the consistency of important conditions, it can approach or find the cause of the phenomenon [46]. That is to identify the combination and core conditions of high (or low) GTFP in the region, providing reference for cities with different development characteristics to enhance their GTFP.

3.2. Sample Selection and Data Sources

This article collects data from 27 cities in the Yangtze River Delta urban agglomeration, and the sample size meets the requirements of the QCA method. Part of the data used in this paper comes from the annual statistical yearbook of each city, China Energy Yearbook, China Environment Yearbook, and the China National Intellectual Property Administration. In addition, the data on "digital economic environment" comes from the "Urban Digital Development Index 2020" released by H3C Group. The data on "business environment" comes from the "China Business Environment Index Blue Book (2020)" jointly released by the China International Science Exchange Foundation, China Development and Reform Press, Tsinghua University Institute of Social Governance and Development, and other institutions. The data on "inclusive finance" comes from the "Digital Inclusive Finance Index (Fourth Issue)" compiled by the Digital Finance Research Center of Peking University. The data on "digital transformation" comes from the "Digital Transformation Index Report (2020)" released by Tencent Research Institute.

3.3. Measurement and Calibration

3.3.1. Results

This article calculates the green total factor productivity of 27 prefecture level cities in the Yangtze River Delta urban agglomeration using MaxDEA software. The calculation of GTFP index includes two types of indicators: input and output. Input indicators include labor input, expressed as the number of employees per unit at the end of the year [47]; The total amount of energy input, water supply, gas supply, and total social electricity consumption are represented [47]; Capital investment is based on the fixed capital stock of cities estimated using the perpetual inventory method in 2005. Output indicators include expected output and unexpected output, with expected output being urban GDP; The unexpected output is industrial

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waste (wastewater discharge, sulfur dioxide, dust) [47]. Missing values are filled in using the mean method.

3.3.2. Precedent Conditions

This article summarizes the indirect factors (economic environment, policy systems, etc.) that affect the green total factor productivity of the Yangtze River Delta urban agglomeration as macroeconomic environmental factors, namely the digital economic environment, measured by the urban digital development index. The government factor, namely the degree of improvement in the business environment, is measured using the China Business Environment Index. Summarize the direct factors that affect the green total factor productivity of the Yangtze River Delta urban agglomeration (such as technological innovation, capital investment, industrial upgrading, digital transformation, etc.) as effective market factors. Specifically, technological innovation is measured by the number of patent authorizations in each city using the output method. The investment in inclusive finance is measured using the Digital Inclusive Finance Index. Industrial upgrading is measured by the ratio of the added value of the tertiary industry to the added value of the secondary industry in each region. Digital transformation is measured using the Digital Transformation Index released by Tencent Research Institute.

3.3.3. Data Calibration and Descriptive Statistics

Calibration of antecedent conditions and results is a prerequisite for necessity analysis. There is no established measurement standard for defining high and non high green total factor productivity, promising government, and efficient market. The evaluation of regional green total factor productivity, the level of effective government and market among cities is also relative, and this article is suitable for using sample based relative position calibration [48]. Using the direct calibration method, the percentiles of the sample data are set as anchor points for complete membership, intersection, and complete non membership, with "complete membership" selecting 95% of the sample data, "complete non membership" selecting 5% of the sample data, and "intersection" selecting digits. To avoid ignoring cross values, add 0.001 [49] to the value of 0.5. The calibration anchor points and descriptive statistics of the antecedent conditions and results are shown in Table 1.

Table 1. Collection, calibration, and descriptive statistics

Collection	Fuzzy set calibration			Descriptive Analysis			
	non-membership	crossover point	full-membership	Mean	SD	Min.	Max.
GTFP	0.969	1.009	1.086	0.4856	0.3029	0.04	0.98
Digital Economic	38.74	64.2	86.55	0.4993	0.2805	0.03	0.97
Business Environment	51.933	62.99	77.331	0.5327	0.3008	0.03	0.96
Technological Innovation	175.7	1493	7943.2	0.4349	0.3104	0.04	0.98
Capital Investment	259.852	293.206	318.72	0.5049	0.2981	0.04	0.99
Industrial Upgrading	0.89	1.113	2.127	0.4464	0.2821	0.04	0.99
Digital Transformation	2.3	14	25.7	0.5	0.3391	0.03	0.97

4. Data Analysis Results

4.1. Necessity Analysis

The QCA method first needs to analyze the necessity of individual conditions. As shown in Table 2, the consistency of the necessity for high/non high green total factor productivity in the Yangtze River Delta region under a single condition is generally low (all<0.9), indicating that there is no necessary condition for producing high/non high green total factor productivity in the Yangtze River Delta region.

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Table 2. fsQCA necessity test for individual conditions

Antecedent condition	Result	
	High GTFP capability	Low GTFP capability
High Digital Economic	0.717	0.614
Low Digital Economic	0.622	0.706
High Business Environment	0.764	0.601
Low Business Environment	0.54	0.686
High Technological Innovation	0.658	0.513
Low Technological Innovation	0.648	0.775
High Capital Investment	0.701	0.598
Low Capital Investment	0.594	0.68
High Industrial Upgrading	0.657	0.573
Low Industrial Upgrading	0.688	0.752
High Digital Transformation	0.716	0.579
Low Digital Transformation	0.584	0.703

4.2. Configurations Analysis

This article uses the fsQCA method to analyze the configuration of the synergy between the government and the effective market that generates high (or non high) green total factor productivity in the Yangtze River Delta region, and finds its asymmetric causal relationship.

4.2.1. Government and Market Configuration for Generating Regional High GTFP

Table 3. Configurations for achieving high/non high GTFP

Antecedent condition	High GTFP configuration	Low GTFP configurations				
	M1	NM1a	NM1b	NM2	NM3a	NM3b
1.Macroeconomic Environment						
Digital Economic	●	⊗	⊗	●	●	●
2. Active Government						
Business Environment	●	⊗	⊗	⊗	●	●
3.Efficient Market						
Technological Innovation	●		⊗	⊗	●	
Capital Investment	●	⊗	⊗	●		●
Industrial Upgrading	●	●		●	⊗	⊗
Digital Transformation	●	⊗	●	●	⊗	⊗
Consistency	0.816	0.952	0.929	0.947	0.957	0.915
Original coverage	0.532	0.374	0.338	0.284	0.336	0.366
Unique coverage	0.532	0.1	0.0216	0.026	0.005	0.017
Overall consistency	0.816	0.905				
Overall coverage	0.532	0.567				

Note:●= Core conditions exist; ⊗= Missing core conditions; ●= Auxiliary conditions exist; ⊗= Missing auxiliary conditions.

Considering that there are 27 important cases in this article, the frequency threshold of the cases is set to 1, the original consistency threshold is set to 0.8, and the PRI consistency threshold is set to 0.7 [48] when conducting configuration adequacy analysis. When it comes to counterfactual analysis, it is assumed that the presence or absence of a single antecedent condition can contribute to high regional green total factor productivity (due to the lack of

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evidence and literature on the exact direction of antecedent conditions affecting results). As shown in Table 3, this article finds a configuration of government market synergy, that is, the digital economy leading industrial upgrading (M1) can generate regional high green total factor productivity. The core conditions are a high digital economic environment and advanced industrial structure, while the auxiliary conditions are a high business environment and high-tech innovation. The representative cities are Shanghai and Hangzhou, with all conditions ranking in the top one or two, reflecting a high degree of synergy between the proactive government and the efficient market.

4.2.2. Government and Market Environment for Generating Regional Non-high GTFP

This article analyzes the collaborative ecology between government and market that generates non high green total factor productivity, and finds that five configurations generate non high green total factor productivity (see Table 3). This reflects a strong causal asymmetry. According to the core conditions, NM1a and NM1b can be grouped together, and NM3a and NM3b can be grouped together, forming a second-order equivalent configuration [49].

Configuration NM1a and NM1b show that high green total factor productivity cannot be achieved when most collaborative conditions perform poorly (missing). Even if certain conditions are favorable (such as the advanced industrial structure in NM1a configuration and the digital transformation in NM1b configuration).

Configuration NM2 shows that the lack of a business environment as the core condition and technological innovation as the auxiliary condition, while the configuration with high digital transformation and advanced industrial structure, the green total factor productivity is not high. In the absence of a favorable business environment, the cost of industrial upgrading and digital transformation investment will increase. The "too much is too little" effect can also lead to low efficiency in product research and development [43]. These factors will all reduce the output capacity of technological innovation, resulting in lower green total factor productivity.

Configuration NM3a and NM3b show that a high digital economy and digital transformation lack a core condition, and a collaborative ecosystem with high business environment, high capital investment, high technological innovation, and advanced industrial structure lacks auxiliary conditions, resulting in low green total factor productivity. Firstly, it indicates that the digital economy of the Yangtze River Delta urban agglomeration is still in its early stage of development, and the existence of the "disruptive innovation" effect [20] has suppressed the improvement of green technology efficiency. Secondly, a better business environment makes resource competition among cities in the region more intense, and the government's tangible hands may also lead to inefficient resource allocation, thereby reducing green total factor productivity. Thirdly, technological innovation needs to be matched with the structure of factor endowments, otherwise it will weaken the inherent driving force of technological innovation [31]; Taking economic growth as the goal will also be detrimental to the utilization of limited resources and the development of the ecological environment[32], thereby reducing the level of GTFP.

4.2.3. Robustness Testing

This article conducts a robustness test on the configuration of government market synergy conditions that generate high green total factor productivity. QCA is a set theory method that is considered robust when there is a subset relationship between the results produced by slight changes in the operation, and it does not change the substantive interpretation of the research findings [48]. Increase the threshold for case frequency from 1 to 2, resulting in one configuration that is basically consistent with one solution in the existing configuration. The above robustness test shows that the results of this article are relatively robust.

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5. Conclusion

5.1. Research Conclusion

This article is based on the perspective of complex systems and uses the QCA method to discover the diverse paths through which various factors of active government and efficient market affect green total factor productivity from a configuration perspective. Firstly, this article finds that a single active government and efficient market conditions are not necessary conditions for generating high green total factor productivity, but require a high degree of synergy between active government and efficient market. The proactive government is mainly reflected in creating a digital economy environment and optimizing the business environment. The effective market is mainly reflected in attracting continuous input of factors, promoting industrial upgrading and digital transformation, activating the innovation drive and vitality of market entities, and ultimately improving green total factor productivity. Secondly, this article identified five configurations of government and market conditions that generate non high green total factor productivity. The contradiction between the existence and absence of conditions in the configuration reflects a strong causal asymmetry with high GTFP, highlighting the complexity of factors affecting GTFP.

5.2. Theoretical Inspiration

The digital economy environment and business environment created by the government can achieve high-quality regional economic development [50], and effective market entities are the driving force to enhance regional GTFP. In the perspective of complex systems, the various elements that affect regional GTFP are like species, constantly competing or adapting to each other, co evolving, and may evolve into different ecosystems, forming diverse and differential driving paths [51]. Firstly, this article finds that both individual government and market factors are not necessary conditions for high GTFP. It is necessary to systematically analyze the mechanism of interaction between elements, as there is a synergistic (or substitutive) effect between them. Secondly, in terms of research perspective, a configuration perspective is adopted, and the QCA method is introduced to analyze the complex causal relationship between the synergistic impact of government and market on GTFP. So as to provide more detailed guidance on the development characteristics of different cities.

5.3. Practical Inspiration

Firstly, it is necessary to systematically optimize the synergy between a promising government and an effective market. Combine various elements of urban high GTFP into an ecosystem and guide them to cluster towards green industries and industries within the region. To assist in the upgrading of traditional industries, alleviate factor mismatches, and guide core enterprises and small and medium-sized enterprises to build a community with a shared future in the industrial chain. Enable them to cross the threshold of digital economy development by advancing towards industrial advancement and high-end development. Secondly, it is necessary to acknowledge the differences in GTFP among cities due to differences in development stages, industrial foundations, ecological functions, resource endowments, and factor agglomeration capabilities. Each city should focus on differentiated development strategies. Finally, establish a coordinated regional competitive relationship and a sound market economy system. Transforming the competition between cities from dislocation to cooperation and collaboration, gradually deepening their integration into the integrated metropolitan economy of the Yangtze River Delta. Actively guide digital transformation enterprises to focus on core technologies in key areas for deep cultivation and refinement, in order to enhance GTFP.

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5.4. Limitations and Prospects

The limitations of this article mainly lie in: firstly, the availability of data is relatively difficult, so it can only focus on analyzing the static relationship between government and market synergy affecting GTFP. In the future, researchers can further dynamically analyze how government market synergy affects changes in GTFP. This is more helpful in analyzing the differences in the pursuit of improving GTFP among different cities. Secondly, the depth and richness of qualitative analysis using QCA in this article are still lacking. In the future, researchers can further conduct in-depth urban case studies on different influencing configuration paths, in order to reveal the process of promoting the evolution of urban GTFP. Finally, this article focuses on the Yangtze River Delta urban agglomeration. In the future, research on Chinese urban agglomerations can be carried out, incorporating more indicators to stimulate the innovation vitality and drive of market entities, and promote the coordinated development of urban GTFP with low-carbon, high-quality, and sustainable economy.

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