QCA Analysis of the Impact of Digital Economy on Export Technological Complexity: A Study Based on the Social and Economic Data of 31 Provinces in China

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Abstract. The digital economy, characterized by informatization and big data as key factors of production, and relying on digital technologies such as the internet and artificial intelligence, represents a new economic paradigm. Its potential to facilitate the transformation and upgrading of manufacturing industries and to enhance the technological complexity of exports necessitates empirical testing. This paper examines the association between factors related to the digital economy and the technological complexity of exports, drawing upon socioeconomic data from 31 provinces and regions in China in 2021, and employing a fuzzy-set qualitative comparative analysis approach. The findings suggest that the digital economy can indeed foster an increase in the technological complexity of exports. Human capital, research and development (R&D) capabilities, digital infrastructure, financial capital, government scale, and market size all exert a positive influence on the technological complexity of exports. The impact configurations of the digital economy on the technological complexity of exports can be classified into two main types: government-market driven R&D innovation, and digital infrastructure-led multifactor influenced. Within the latter category, four subtypes are distinguished: digital infrastructure single-factor dominance, digital infrastructure-led with weak market, digital infrastructure-led with insufficient government strength, and digital infrastructure-led with weak R&D. In areas with a higher level of digital economy, its influence on the technological complexity of exports is notably more positive. The construction of digital infrastructure and R&D capabilities are core conditions affecting whether a region can achieve a high level of technological complexity in exports. Concurrently, attracting human capital, increasing government support, and expanding market size are also factors that cannot be overlooked.

Keywords: Digital Economy, Export Technological Complexity, Technological-Economic Paradigm, QCA, Regional Social and Economic Data.

1. Introduction

The digital economy, which is driven by iterative innovation of digital technologies such as big data, blockchain, cloud computing, and artificial intelligence, is characterized by information and big data as key production elements. According to the "Analysis of the Digital Economy Situation in 2020-2021" released by the National Industrial Information Security Development Research Center, the digital economy has become a national strategy that injects important impetus to the world's economic recovery and growth in the unexpected COVID-19 pandemic outbreak. The digital economy has gradually become an important part of leading the development of the economic and social sectors, not only serving as a key driver of economic growth but also providing an effective pathway for industrial upgrading and winning international competition.[1] In 2020, China's export value reached 462 million US dollars, ranking first globally. However, challenges such as the rising labor costs in manufacturing, the blockage of key core technologies, and economic impacts from unilateralism, trade protectionism, and the global pandemic era are making the issues within the Chinese manufacturing sector increasingly prominent. The majority of export industries remain at the middle and lower ends of the global value chain, featuring relatively low technological sophistication in exported products. To address this, it is imperative to integrate the digital economy with the real economy, promoting research and development innovation, thereby enhancing the technological complexity of Chinese export products and further elevating China's level of innovation and the quality effects of export trade.

This paper, based on socio-economic data from China's 31 provincial-level administrative regions, analyzes the impact of representative factors of the digital economy on the technological complexity of manufacturing exports. It empirically tests the influence of the digital economy on the competitiveness of manufacturing exports, highlighting the significant practical importance of improving the competitiveness of China's manufacturing exports under the development of the digital economy.[2]

2. Literature Review

2.1. Literature Analysis on the Relationship between Digital Economy and Export Technological Complexity

The digital economy, as an emerging economic paradigm of the new era, is bringing about a silent revolution in traditional manufacturing. The development of the digital economy presents numerous opportunities for the manufacturing industry, offering not only the optimization of production processes, enhancement of efficiency and product quality, but also the acceleration of innovation and research and development activities. Moreover, it contributes to the reduction of production costs and resource consumption, thereby elevating the position of the manufacturing sector within the global value chain.[3] The application of digital technologies has created more opportunities for the manufacturing industry. Through the empowerment of digital technologies, the manufacturing industry can not only optimize production processes and enhance productivity but also achieve personalized customization of products, improve product quality and reliability, thereby increasing the competitiveness of the manufacturing industry.[4] The application of digital technologies can also help the manufacturing industry transform towards high-value-added products, thereby improving its position in the global value chain. For example, 3D printing technology has been widely used in industries such as automotive and aviation, enabling not only the rapid production of product prototypes but also the manufacturing of complex components, enhancing the flexibility and innovation capabilities of the manufacturing industry.

Furthermore, the development of the digital economy can also facilitate the deep integration between the manufacturing and service sectors, leading to a more complex and diverse industrial structure, thereby enhancing industrial competitiveness and the comprehensive strength of the country.[5] The development of the digital economy has facilitated the transformation and upgrading of traditional manufacturing industries, while also increasing the technological content of products. In this process, the boundary between the manufacturing and service sectors has become increasingly blurry, with manufacturing companies no longer satisfied with merely providing physical products but also offering a broader range of services and solutions. For instance, smart manufacturing has become a popular topic in the manufacturing industry, where the application of digital technologies enables automatic scheduling and collaboration among machines, leading to more efficient production and management on the production line.

The development of the digital economy can also promote regional synergy and collaboration.[6] The rapid development of digital technologies offers increased possibilities for coordinated regional development. The application of these technologies can strengthen inter-locality industrial complementarity and collaboration, thereby enhancing the economic strength of regions. For instance, within the manufacturing sector, the advancement of the digital economy can promote the integration and optimization of supply chains, leading to more efficient production and logistics systems. In terms of the service sector, the development of the digital economy can drive the upgrading and transformation of local services to meet the growing consumer demand.

In summary, the digital economy is a fundamental component in driving socio-economic growth and represents a new variable for enhancing the quality and efficiency of manufacturing exports. It also serves as a new engine for promoting coordinated regional development. As the digital economy continues to evolve, the application of digital technologies will play an even more significant role in both manufacturing and service industries, fostering industrial upgrading and transformation. Consequently, enterprises within the manufacturing and service sectors must proactively address the challenges posed by the digital economy. They should seek opportunities within this digital landscape to continuously improve their competitive edge and innovation capabilities, thereby adapting to future market demands.

The complexity of exported technology plays a crucial role in the economic development of a region or country. It not only reflects the technological content and production efficiency of exported products in that region or country but also demonstrates the export structure. The higher the complexity of exported technology, the higher the quality and technological level of the exported products.[7] In recent years, with the development of the digital economy, a significant impact has been observed on the enhancement of the technological complexity of exports. According to empirical studies by Abeliansky et al. (2016) and other scholars, the advancement of the digital economy has been shown to facilitate an increase in the technological complexity of exports. The digital economy influences the technological content and the structure of regional exports through the innovation of business models and improvements in efficiency.

Chinese scholars have also conducted in-depth studies on the factors affecting the technological complexity of exports. Their research indicates that factors such as human capital and the scale of labor can promote the enhancement of the technological complexity of exports. Furthermore, the import volume of service trade, investment in scientific research, and efforts in carbon reduction can also contribute to increasing the technological complexity in service trade exports. Additionally, scholars have studied the pathways through which technological complexity of exports is influenced. Digital trade, by advancing industrial structure upgrades and repositioning the technological complexity of manufacturing exports, supports the positive development of export technological complexity.

In summary, the technological complexity of exports serves as an important indicator of a region's or country's economic development. The growth of the digital economy, improvement of human capital and labor scale, the import volume of service trade, investment in scientific research, and carbon reduction initiatives all contribute to the enhancement of export technological complexity. Concurrently, strengthening intellectual property protection can also assist companies in achieving elevated levels of technological complexity in their exports.[9]

The digital economy refers to economic activities driven by digital technologies, encompassing but not limited to the development of internet technology. With the rapid development of the digital economy, the relationship between it and the technological complexity of exports is increasingly attracting attention. Initially, we need to consider multiple aspects of the digital economy in greater detail. The development of the digital economy involves various facets, including but not limited to the advancement of internet technology. Thus, when studying the relationship between the digital economy and the technological complexity of exports, it is essential to consider various aspects of the digital economy. For instance, internet technology, artificial intelligence (AI), the Internet of Things (IoT), and 5G technology are all critical technologies in the evolution of the digital economy.

Secondly, we require a broader set of indicators to measure the level of development of the digital economy. In past research, the level of internet development has often been used to represent the digital economy. However, the expansion of the digital economy is not only reflected in the internet domain but also includes the development in areas such as artificial intelligence and the Internet of Things. Therefore, a wider range of indicators is needed to gauge the developmental level of the digital economy.

Existing literature has conducted numerous beneficial explorations into the relationship between the digital economy and the high-quality development of the manufacturing industry. The swift progress of the digital economy presents new opportunities for the high-quality development of manufacturing. The evolution of the digital economy enables the manufacturing sector to better utilize digital technologies, enhancing production efficiency and manufacturing quality. Simultaneously, the high-quality development of manufacturing can also promote the growth of the digital economy, particularly in the development of artificial intelligence and related fields.

However, current literature regarding the influence mechanism of the digital economy on the technological complexity of China's exports remains limited. The mechanism effects between the two have not been fully elucidated. Therefore, this article, based on the socio-economic data of 31 provinces and regions in China for the year 2021, explores the impact effects of the digital economy on the technological complexity of China's exports, both regionally and in terms of dimensions. The aim is to expand related literature and provide a reference for subsequent research.

2.2. Analysis of Relevant Research Literature on the Constituent Elements of the Digital Economy.

With the rapid development of digital technology, the digital economy has become an emerging form of economy. Among them, the transformation of the technological economic paradigm is one of the key factors driving the development of the digital economy. Perez and Freeman discuss the technological economic paradigm, stating that it refers to the joint action of technological, social and institutional factors under specific technological conditions, which promotes the transformation of economic structure and form, and satisfies people's value needs. Yang Qingfeng and Li Xiaohua[11] proposed the structure and intrinsic logic of the technological economic paradigm in the digital economy and constructed a relevant framework. Factors such as technology, infrastructure, capital, institutions, and markets constitute the basic framework for the transformation of the technological economic paradigm. The research and development capabilities of digital technology represent the technological dimension, while digital infrastructure such as digital industrialization, internet penetration, and intelligent computers represent the infrastructure dimension. The implementation of relevant institutional policies by local governments represents the institutional dimension, and the market transaction scale of regional digital economies represents the market dimension. The quality and development of the digital economy are influenced by these factors collectively. In specific research, it is necessary to elaborate on factors such as human capital, research and development capabilities, digital infrastructure, government policies, and market scale, and analyze the relationship between the digital economy and these factors. Such research provides a basis for a deeper understanding of the development and driving factors of the digital economy and offers recommendations for policy-making and practice. In this paper, we select human capital, research and development capabilities, digital infrastructure, government policies, and market scale as representative factors for discussing the digital economy.

(1) Human Capital: Human capital is a key element in the development of the digital economy; a high-quality workforce constitutes the foundation of the digital economy's progress. A city or region with an adequate supply of skilled labor is better equipped for higher levels of digital economic development. Therefore, cities and regions need to focus on nurturing and developing human capital.

(2) Research and Development (R&D) Capability: R&D capability is another critical factor in the advancement of the digital economy. Digital technologies, which underpin the digital economy, play a decisive role in the digital transformation of traditional industries and the innovation of business models. High R&D capability in the digital domain can accelerate the technological upgrading of traditional industries and promote service model innovation, thereby fostering the formation and development of the digital economy. Moreover, the progression of the digital economy also requires strengthened international cooperation and protection of intellectual property rights. Cities and regions need to cultivate professionals in the field of digital technology, enhance digital R&D capabilities, and strengthen the protection of intellectual property to ensure the innovation and development of digital technologies.

(3) Digital Infrastructure: Digital infrastructure is an important pillar for the digital economy, including hardware equipment, software technology, and relevant institutional norms. A well-established digital infrastructure can provide the necessary conditions for the development of the digital economy and expedite its progression. As such, cities and regions need to strengthen the construction of digital infrastructure to enhance its quality and coverage.

(4) Government Policy: Government policies can play a supportive role in the development of the digital economy. Governments can promote the operation of factor markets through effective institutional arrangements, producing positive spillover effects and propelling the digital economy. Therefore, cities and regions must enhance the management and regulation of government size, and improve governmental efficiency and service quality.

(5) Market Size: Market size is one of the significant factors in the development of the digital economy. The digital economy is characterized by economies of scale; a large market size can stimulate scale effects in the digital economy and attract more resources to enter the digital domain. However, the influx of a vast number of factors might also lead to a decline in corporate quality within the market, necessitating the formulation of policies to maintain healthy market development. Consequently, cities and regions should strengthen the management and regulation of market size to promote the healthy development of the digital economy.

In summary, the development of the digital economy requires cities and regions to focus on core areas such as human capital, R&D capability, digital infrastructure, government policy, and market size, strengthening the management and regulation in these domains to foster the healthy progression of the digital economy.

For this purpose, this article selects data on the five factors of human capital, R&D capability, digital infrastructure, government policy, and market size to represent the regional level of digital economy development. The specific benchmarks are shown in Table 1:

Table 1: Selection Criteria for Representative Factors of the Digital Economy(The last column in the table is represented in the form of references)

Description Variables of the Digital Economy	CONNOTATION	REFERENCE BASIS
Human capital	Sources of talent in a market economy	Dong, P.; Zhu, Y.; Duan, S.; Wu, M.; Bao, J(2023)
Research and Development (R&D) Capability	Drivers of the digital economy	David J.(2018)
Digital Infrastructure	Hardware foundation of the digital economy	Z. Li and Y. Liu(2021)
Government Policy	Intrinsic drivers of the digital economy	Lin Liang, Yan Li(2023)
Market Size	Necessary factors for the development of the digital economy	Huang, S.; Ye, W.; Han, F(2023)

In conclusion, studies on the impact of individual factors on the quality of the digital economy provide a basis for the conditional selection of this research and lay a theoretical foundation for discussing the representative factors of the digital economy at the inter-provincial level within the framework of techno-economic paradigm theory. However, related studies have not delved into and explained the complex interrelationships among these factors or their synergistic impact on the complexity of manufacturing exports. A configurational perspective focuses on the synergistic effects of multiple system elements on outcomes, aiming to investigate the complex causal relationships among relevant factors, and is suitable for analyzing the impact of factors involved in techno-economic paradigm theory on the technological complexity of manufacturing exports.

Therefore, this article builds upon the techno-economic paradigm theory and employs the Qualitative Comparative Analysis (QCA) method to conduct typological and configurational analyses. It introduces a configurational comparative approach based on the perspective of configurational analysis to explore the possible causal mechanisms of how factors related to the digital economy affect the technological complexity of manufacturing exports. Specifically, the paper investigates the synergistic dynamics and configurational fit among five conditional factors: human capital, R&D capability, digital infrastructure, government size, and market size. By analyzing these elements, the article aims to elucidate the specific practical pathways through which the digital economy influences the technological complexity of manufacturing exports.

3. Research Methodology and Empirical Analysis

3.1. Qualitative Comparative Analysis (QCA)

Fuzzy Set Qualitative Comparative Analysis (fsQCA) is a qualitative comparative methodology based on fuzzy set theory. It is suited for studies with small samples and multiple variables, and it can accommodate interactions between variables as well as nonlinear relationships. [17]

This research will collect data on human capital levels, research and development (R&D) capability indicators, the state of digital infrastructure, government size, and market size from various provincial divisions, converting these data into fuzzy sets. Subsequently, by constructing a truth table of causal relationships, the study will calculate the coverage and consistency of each combination in terms of its impact on the technological complexity of exports. Then, using the Boolean logic regression analysis of fuzzy sets, the study will identify combinations with relatively high coverage and consistency.

Finally, the research will interpret and validate the findings, conducting an in-depth analysis of the relationships and combinations of the various factors. Through this qualitative comparative analysis methodology, a comprehensive understanding can be gained regarding the influence of human capital, R&D capability, digital infrastructure, government size, and market size on the technological complexity of exports. This approach will provide a scientific basis for the formulation of related policies.

3.2. Case Samples and Data

This study selects socio-economic data from 31 provincial administrative regions in China for the year 2021 as its sample. The sample covers most of China's economic areas, and the variables related to the case regions exhibit considerable variation, meeting the requirements for heterogeneity in case selection.

(1) Outcome Variable: Technological Complexity of Manufacturing Exports (TS)

Within the system of intra-product division of labor, economically advanced regions typically engage in sectors with higher technological complexity, such as research and development, design, and production of core components. In contrast, less developed economic regions often participate in low-technological complexity sectors like processing and assembly. Based on this characteristic, Hausmann et al. (2007) constructed the Technological Complexity of Exports using per capita GDP and regional industry export values to characterize a country or region's division of labor status and industrial competitiveness in the global value chain. Drawing on the method of Hausmann et al. (2007), the calculation formula for the Technological Complexity of Manufacturing Exports (TS) is as follows:

$$PRODY_k = \sum_i \frac{x_{ik}/X_i}{\sum_i x_{ik}/X_i} Y_i \tag{1}$$

$$ESI_i = \sum_k \frac{x_{ik}}{X_i} PRODY_k \tag{2}$$

In the formula, i represents the province, and k represents the sub-industry within the manufacturing sector 1. ESI denotes the technological complexity of the exported product, while Xik/Xi represents the proportion of exports of sub-industry k in province i relative to the total exports of that province. Here, Yi represents the labor productivity of the entire manufacturing industry in province i, which is proxied by the ratio of the total output value of the manufacturing industry in each province to the average number of employees in the manufacturing industry for the year.

The calculation of the manufacturing export complexity for the 31 provincial administrative regions of China in 2021 is presented in Table 2 as follows:

Table 2: Statistical Table of Manufacturing Export Complexity in 31 Provincial-level Administrative Regions of China in 2021.

Administrative region	**Export Complexity**	**Administrative region**	**Export Complexity**	**Administrative region**	**Export Complexity**	**Administrative region**	**Export Complexity**
Anhui	72911.289	Hebei	69917.656	Liaoning	73501.75	Sichuan	74072.085
Beijing	88866.140	Henan	73539.56	Inner Mongolia	61362.929	Tianjin	77103.304
Fujian	73893.968	Heilongjiang	68981.820	Ningxia	56033.933	Tibet	71656.898
Gansu	70606.218	Hubei	69844.06	Qinghai	72205.398	Xinjiang	71910.164
Guangdong	75345.164	Hunan	71615.757	Shandong	70919.484	Yunnan	66826.039
Guangxi	74289.257	Jilin	66324.664	Shanxi	74929.820	Zhejiang	73435.523
Guizhou	64406.570	Jiangsu	73441.257	Shaanxi	75508.906	Chongqing	75799.453
Hainan	80407.382	Jiangxi	70854.703	Shanghai	73908.843		

(2) Conditional Variables

With the continuous development of digital technology, the digital economy has become an important direction for the development of various industries. Understanding and assessing the impact of different conditional variables on the digital economy is of great significance for promoting the development of the digital economy and optimizing economic structures. This paper will focus on the following conditional variables from an industry professional perspective: human capital, research and development (R&D) capability, digital infrastructure, government size, and market size. A detailed explanation of the interpretation, measurement units, data sources, and descriptive statistical analysis of these variables will be provided.

Human capital refers to the accumulation and improvement of human resources, typically measured by the level of education. Cities with higher education levels possess a higher quality workforce, which is crucial for the talent demands of the digital economy. This paper measures human capital status using the number of undergraduate degree holders, which is a commonly used indicator.

The R&D capability is a manifestation of the capacity to perform research and development, with patents being one of the significant indicators. The paper uses the number of digital technology patent applications per capita to measure a city's R&D capability, another widely used indicator. This indicator eliminates the influence of population size and more accurately reflects the overall R&D capability of a city.

Digital infrastructure is foundational for the development of the digital economy, focusing on information infrastructure such as internet broadband and data centers. This paper uses the number of internet broadband access ports to gauge the state of digital infrastructure, which is also a commonly used indicator.

Government size refers to the size of government institutions and the role of government in the economy. The paper uses spending on science and technology to reflect government size, which is one of the common indicators. Government expenditure can directly promote technological innovation and industrial transformation and upgrading, which is of great importance for the development of the digital economy.

Market size refers to the size of the local market, which also has significant implications for the development of the digital economy. This paper uses local GDP to measure the size of the local market, which is a widely used indicator. The market potential of the digital economy is to gradually realize the digital transformation of various industries; therefore, the size of the market is crucial for the development of the digital economy.

Overall, the impact of different conditional variables on the development of the digital economy is multifaceted and necessitates a comprehensive assessment from multiple dimensions. Cities should further strengthen the construction of digital economy-related conditional variables to foster the rapid development of the digital economy and optimize the economic structure. The paper provides a detailed explanation of the interpretation, measurement units, data sources, and descriptive statistical analysis (including mean, standard deviation, maximum, and minimum values) of these variables as shown in the following Table 3:

Table 3: Descriptive Statistics Table

Variable	Description	Unit	Data Source	Descriptive Statistics				Theoretical Basis
				Mean	Standard Deviation	Maximum	Minimum	
Human capital	Number of Undergraduate Graduates	People	China Statistical Yearbook	135648.2903	80753.41116	302728.00	6020.00	STUETZER M et al.(2018)
The R&D capability	Patent Grants per Resident	Pieces/ 10,000 People	China Statistical Yearbook	0.0022	0.00203	0.007437231	0.000466544	WANG Jian et al.(2020)
Digital infrastructure	Internet Broadband Access Ports	Ten Thousand Units	China Statistical Yearbook	3051.7710	2099.21463	8653.20	219.00	WEN Jun et al.(2019)
Government size	Scientific and Technological Expenditures	Billion Yuan	China Statistical Yearbook	187.1571	209.49964	955.73	8.99	THORNTON J(2010)
Market size	Technology Market Turnover	Billion Yuan	China Statistical Yearbook	8804445.323	12902444.85	63161622.00	7783.00	QIU Binet al.(2010)
Export Technological Complexity	Calculated Result		China Statistical Yearbook	67371.42	5452.32	77290.12	47123.93	Hausmann, R. et al.(2007)

(3) Variable Calibration

Variable calibration plays a significant role in set analysis and operations. It is a necessary step that involves transforming the initial data from the sample into set membership scores that can reflect the degree of membership relations between sets. The purpose of variable calibration is to determine the degree of membership of each case on the corresponding variable based on the positioning of anchors.

Ragin [24] suggests that when discussing how to determine the specific locations of the three qualitative anchors, it is best to rely on well-established theoretical knowledge or empirical evidence. However, due to the lack of operationally viable theories and empirical guidance in social science, this paper refers to previous research and calibrates based on the data characteristics of the cases themselves, employing the method of direct calibration. Direct calibration involves setting the three anchors of the conditional and outcome variables at the 95th percentile, 50th percentile, and 5th percentile of the sample data, which respectively correspond to full membership, the crossover point, and full non-membership. The specific calibration information is presented in the Table 4 below:

Table 4: Information Calibration Table

Conditional Variables and Outcome Variables	Target Set	Calibration		
		Full Membership	Intersection Point	No Membership
Export Technological Complexity (TS)	High export technological complexity	76841.8188	68427.5313	52388.3391
Human Capital (HC)	Adequate human capital	289954	124729	7942.4
Research and Development Capability (RDC)	Strong research and development capability	0.0066	0.0012	0.0005
Digital Infrastructure (DI)	Comprehensive digital infrastructure	7796.22	2368.8	335.28
Government Size (GS)	Large government size	732.926	101.76	9.932
Market Size (MS)	Large market size	44867934	3797786	66488.8

4. Results Analysis

4.1. Necessity Analysis

If a factor is always present when an outcome occurs, it can be considered necessary for the production of that outcome. The consistency index indicates the degree to which cases within the same configuration belong to that pathway, and it is an important criterion for evaluating whether a conditional variable is necessary. Referencing existing research, this paper uses the fsQCA 3.0

software to perform an analysis of necessary conditions and sets the consistency threshold for necessary conditions at 0.9 within the software. The results are presented in the Table 5 below:

Table 5: Necessity Results Test Table

Conditional Variables	High Export Technological Complexity		Non-High Export Technological Complexity	
	Consistency	Coverage	Consistency	Coverage
Human Capital	0.742	0.742	0.688	0.682
～Human Capital	0.682	0.688	0.740	0.740
The R&D capability	0.729	0.780	0.616	0.653
～The R&D capability	0.676	0.640	0.792	0.743
Digital Infrastructure	0.764	0.770	0.685	0.684
～Digital Infrastructure	0.687	0.688	0.770	0.764
Government Size	0.682	0.785	0.596	0.680
～Government Size	0.722	0.643	0.812	0.717
Market Size	0.668	0.829	0.563	0.692
～Market Size	0.752	0.634	0.861	0.720

Based on the above table, it can be observed that for both high and non-high export technological complexity, the consistency values of the single conditional variables with the outcome variables cannot reach 0.9. This indicates that the individual factors included in the digital economy representational factors are not necessary conditions for the occurrence of the outcome variables. Therefore, further analysis of the synergistic mechanism of the five conditional factors, namely human capital, research and development capability, digital infrastructure, government size, and market size, is necessary.

4.2. Configurational Analysis

3.2.1 Outcome Interpretation - Construction of a Results Table

This paper conducts a configurational analysis using fsQCA 3.0 and sets the original consistency threshold at 0.9. Given that Greckhamer et al. (2018) noted configurations with PRI scores below 0.5 exhibit significant inconsistency, this paper establishes a consistency threshold for configurations with high export technological complexity at 0.50, and a case frequency threshold at 0.465 (15% of the case sample size). For the configurations with non-high export technological complexity, the PRI consistency threshold is set at 0.50, with a case frequency threshold of 1. The results are presented in Table 6.

From the necessity analysis previously discussed, we know that none of the conditional variables reached a consistency or coverage exceeding 0.90; thus, there are no necessary conditions. According to the results of the configurational analysis, the impact of the representative elements of the digital economy on high export technological complexity can be summarized into five pathway models, while the impact on non-high export technological complexity can be summarized into three pathway models. The overall solution's consistency for high export technological complexity configurations is 0.943, far exceeding the acceptable level of 0.8, with an overall coverage of 0.686, indicating that the five configurations explain more than 68.6% of the reasons for achieving high export technological complexity. Therefore, these five configurations can be viewed as a sufficient condition combination for achieving high export technological complexity. Among them, H1a, H1b, H1c, and H1d share the same core condition, thus constituting a second-order equivalent configuration [26]. The overall solution's consistency for configurations with non-high export technological complexity is 0.829, also above the acceptable level of 0.8, with an overall coverage of 0.67, indicating that the three configurations explain more than 67% of the reasons for achieving high export technological complexity. Consequently, these three configurations can also be considered a sufficient condition combination for achieving high export technological complexity. The configurations P1a, P1b, and P1c share the same core condition, forming a second-order equivalent configuration.

The specific results of the qualitative comparative analysis are shown in the Table 6 below:

Table 6: Configuration for Achieving High Export Technological Complexity and Non-High Export Technological Complexity in fsQCA

Conditions	High Export Technological Complexity					Non-High Export Technological Complexity		
	H1a	H2	H1b	H1c	H1d	P1	P2	P3
Human Capital	x	⊗	◎	◎	◎		x	x
The R&D capability	⊗	●	◎	◎	⊗	⊗	⊗	⊗
Digital Infrastructure	●	⊗	●	●	●	⊗	⊗	⊗
Government Size	⊗	●	◎	⊗	◎	x		x
Market Size	⊗	●	⊗	◎	◎	x	x	
Consistency	0.950	0.993	0.968	0.959	0.961	0.828	0.825	0.821
Raw Coverage	0.395	0.317	0.430	0.378	0.349	0.640	0.627	0.612
Unique Coverage	0.105	0.057	0.046	0.026	0.018	0.035	0.022	0.007
Overall Consistency	0.943					0.829		
Overall Coverage	0.685					0.670		

Note:●represents the presence of a core condition,⊗represents the absence of a core condition,◎represents the presence of a peripheral condition,x represents the absence of a peripheral condition, and blank space indicates the presence or absence of a variable is irrelevant.

3.2.2 Analysis of Configurations for High Export Technological Complexity

According to Table 6, the regional types that affect high export technological complexity fall into two main categories: government-market driven R&D innovation type and digital infrastructure-led multifactorial influence type. The latter can be further divided into four subtypes: single-factor digital infrastructure-dominated, digital infrastructure-led with weak market, digital infrastructure-led with insufficient government effort, and digital infrastructure-led with weak R&D capability. The paper will now specifically analyze the characteristics and causes of the different pathways:

(1) Government-Market Driven R&D Innovation Type

This corresponds to configuration H2, which has a consistency of 0.994, indicating that the configuration is valid since the consistency is greater than 0.75. The original coverage is 0.318 and the unique coverage is 0.058, suggesting that 5.8% of regions can be explained by the government-market driven R&D innovation configuration. The pathway represented by configuration H2 is driven mainly by the area's export technological complexity, which is primarily driven by excellent digital technology R&D level and massive market size. This pathway reflects the joint driving force of R&D capability and market size on the development of regional export technological complexity. The technology R&D, as the starting point of the digital economy, keeps propelling the iteration of digital technologies, providing the driving force for the development of the digital economy. A vast market size provides the space for industrialization and commercialization of digital technology, which, combined with R&D capability, leads to the emergence of high regional export technological complexity. This configuration indicates that regions with broad market size and strong government support to boost R&D capability can achieve high levels of export technological complexity.

Typical regions corresponding to this configuration include Sichuan, Hubei, Henan, etc. They possess significant market potential and government-driven innovation development. However, compared to developed coastal provinces, their digital infrastructure construction might not be as advantageous. Due to limitations like topography, economic development level, and resource distribution, the coverage and quality of their digital infrastructure might still need improvement.

For example, although Sichuan Province is actively developing into a science and technology innovation center in the Western region, with several key national laboratories and innovative enterprises, in the past years, Sichuan and other inland provinces may not have been as advanced as coastal provinces like Guangdong, Jiangsu, and Zhejiang in terms of 4G coverage and internet penetration rates. Additionally, within a province, there may also be imbalances in the development of digital infrastructure. For instance, the digital infrastructure in provincial capitals or specific economic development zones may be more advanced while remote areas may lag.

(2) Single-Factor Digital Infrastructure-Dominated Type

This corresponds to configuration H1a, which has a consistency of 0.950, indicating that the configuration is valid since the consistency is greater than 0.75. The original coverage is 0.396 and the unique coverage is 0.105, suggesting that 10.5% of regions can be explained by the single-factor digital infrastructure-dominated configuration. This pathway indicates that a combination of antecedent variables centered on the vigorous development of digital infrastructure can lead to regions with high levels of export technological complexity.

Typical regions corresponding to this configuration include Shaanxi, Anhui, Jilin, etc. In China, the economically developed eastern coastal regions, such as the Pearl River Delta, Yangtze River Delta, and Beijing-Tianjin-Hebei region, generally have high export technological complexity due to superior digital infrastructure, abundant human resources, strong R&D capabilities, significant government support, and massive market size. In contrast, some areas in the central, western, and northeastern parts of China may not match the developed eastern regions in some respects. Nevertheless, even in these inland regions, the government is actively promoting the construction of digital infrastructure to support local industrial upgrading and enhance the quality of product exports. For example, in Heilongjiang, Shaanxi, and other places, there are government-led digital demonstration cities or zones. Although the export technological complexity of these areas may not compete with the eastern coastal regions, the construction of digital infrastructure plays an important role in local economic transformation and the enhancement of export quality.

(3) Digital Infrastructure-Led with Weak Market Type

This corresponds to configuration H1b, which has a consistency of 0.968, indicating that the configuration is valid since the consistency is greater than 0.75. The original coverage is 0.430 and the unique coverage is 0.046, suggesting that 4.6% of regions can be explained by the digital infrastructure-led with weak market configuration. This pathway indicates that a combination of antecedent variables with strong digital infrastructure development as the core condition, considering human capital, R&D capability, government size as secondary conditions, with only the market size being weak, can lead to regions with high levels of export technological complexity.

Typical regions corresponding to this configuration include Chongqing, Guizhou, Liaoning, etc. Some western regions, led by Chongqing, have recently received strong government support, and their digital economy infrastructure has developed rapidly, such as the construction of cloud computing and big data centers. At the same time, these regions have made certain progress in high-tech industries like electronic information and biomedicine. However, due to geographic location and historical development level, their market size and international influence may not match those of the eastern coastal regions. Some traditional industrial bases, led by Liaoning, are undergoing industrial transformation and upgrading, such as Shenyang and Dalian in the northeast. They may improve the export technological complexity of the manufacturing industry by introducing and developing digital technologies and smart manufacturing. Although the infrastructure and technological innovation capabilities of these areas are improving, the growth of market size and the pace of internationalization may be relatively slow.

(4) Digital Infrastructure-Led with Insufficient Government Effort Type

This corresponds to configuration H1c, which has a consistency of 0.959, indicating that the configuration is valid since the consistency is greater than 0.75. The original coverage is 0.378 and the unique coverage is 0.026, suggesting that 2.6% of regions can be explained by the digital infrastructure-led with insufficient government effort configuration. This pathway indicates that a combination of antecedent variables with strong digital infrastructure development as the core condition, considering human capital, R&D capability, market size as secondary conditions, with only the government support being weak, can lead to regions with high levels of export technological complexity.

Typical regions corresponding to this configuration include various minority autonomous regions. The Chinese government's support for the digital economy is generally strong, and most regions invest significantly in the digital economy. The reason for the weaker governmental support in the minority autonomous regions could be due to their relatively smaller fiscal expenditures and population sizes compared to other provinces. Moreover, they may have certain advantages in natural resources, geographic location, and historical industrial base, which can attract enterprises to invest and develop a certain level of technological competitiveness based on these advantages. The technological improvements in these regions rely more on the development of the tourism industry.

(5) Digital Infrastructure-Led with Weak R&D Capability Type

This corresponds to configuration H1c, which has a consistency of 0.961, indicating that the configuration is valid since the consistency is greater than 0.75. The original coverage is 0.349 and the unique coverage is 0.018, suggesting that 1.8% of regions can be explained by the digital infrastructure-led with weak R&D capability configuration. This pathway indicates that a combination of antecedent variables with strong digital infrastructure development as the core condition, considering human capital, government support, market size as secondary conditions, with only the R&D base being weak, can lead to regions with high levels of export technological complexity.

Typical regions corresponding to this configuration include Hainan, Yunnan, etc. These areas have seen rapid economic development in recent years, with significant government and national support. The development of digital economy infrastructure is progressing quickly, but due to weaker economic strength compared to coastal areas and weak historical bases, they have fewer reserves of universities and research institutions, hence their innovation capability is relatively poor.

3.2.3 Analysis of Configurations for Non-High Export Technological Complexity

As seen in Table 6, configurations P1a, P2b, P3c show that the lack of R&D capability and digital economy infrastructure construction are essential common issues in regions with non-high export technological complexity. The strength of R&D capability directly affects the innovation ability of enterprises and the technological level of products, while the digital economy infrastructure is an essential condition for the efficient operation of modern enterprises and participation in international competition. Neither can be absent. Without strong R&D support, enterprises find it challenging to break through technological bottlenecks and launch high-end products. Without digital economy infrastructure, the efficiency of enterprises in production, management, and market development is significantly reduced, affecting overall competitiveness. Therefore, the lack of R&D capability and digital economy infrastructure will directly lead to the inability to improve export technological complexity and have a negative impact on the economic development and international competitiveness of the country or region. In addition to the lack of these two core conditions, the three configurations each lack one of the peripheral conditions: human capital, government support, and market size, which also shows that on the basis of improving R&D capability and optimizing digital economy infrastructure construction, attracting human capital, increasing government support, and expanding market size should not be ignored.

4.3. Robustness Test

To enhance the reliability of the research conclusions, a further robustness test is required. Firstly, the PRI consistency threshold is raised to 0.70, while all other treatments remain unchanged. The results show that the overall consistency changed from 0.943 to 0.947, with almost no change in consistency; aside from some changes in peripheral conditions, other configuration conditions did not change significantly. However, these changes are not sufficient to support a new, completely different substantive outcome and interpretation, which is consistent with the robustness test criteria for QCA results proposed by Schneider and Wagemann [27]. This indicates that the analysis results of this study are reasonably robust.

5. Research Conclusions and Implications

5.1. Research Conclusions

Through the analysis of the factors influencing high export technological complexity, this paper identifies five configurations within two major impact types: government-market driven R&D innovation and digital infrastructure-led multifactorial influence. Further configurational analysis of regions with non-high export technological complexity reveals that the lack of R&D capability and digital economy infrastructure are the primary causes for this phenomenon. Therefore, by synthesizing configurational analyses of both high and non-high export technological complexity, we can conclude that enhancing R&D capabilities and the construction of digital economy infrastructure are key elements in vigorously developing the digital economy to improve regional export technological complexity. This paper, employing a fuzzy set qualitative comparative analysis method, constructs and measures digital economy and export technological complexity indicators for 31 provinces (and cities) in China in 2021. Based on socioeconomic data, it empirically tests the relationship between the digital economy and export technological complexity. The research demonstrates that the digital economy can promote R&D innovation and export technological complexity, with R&D innovation and digital economy infrastructure being the main channels through which the digital economy affects export technological complexity. Indicators related to the digital economy, such as human capital, R&D capability, digital infrastructure, government size, and market size, collectively have a positive impact on export technological complexity. Regions with high levels of digital economy have a more significant role in promoting high export technological complexity. Investments in R&D in the field of digital technology should be increased, enterprises should be encouraged to carry out digital integration innovation, and the construction of digital infrastructure in regions with lower levels of digital economy development should be strengthened.

5.2. Research Implications

(1) Strengthen Digital Infrastructure Construction to Enhance Core Competitiveness

With the rapid development of the global digital economy, the construction and improvement of digital infrastructure have become a key focus for all countries. As the foundation of digital economy development, the construction, perfection, and optimization of digital infrastructure are crucial for enhancing a country's core competitiveness and innovation capability. Going forward, the digital economy will become the main driver of economic development, and countries should strengthen their digital infrastructure to digitalize and visualize the mobility of factor endowments.

Governments are important promoters and investors in the construction of digital infrastructure. At this stage, governments need to increase their investment and support for digital technology to promote the development of digital infrastructure. Governments should advance the construction of critical facilities such as 5G base stations, computer science research centers, and artificial intelligence research institutes, and continuously push for breakthroughs in key algorithms and core technologies. Governments should also focus on the construction and improvement of information infrastructure like big data to solidify the foundation of digital economy development.

(2) Promote the Construction of Technology Innovation Platforms and Build a Talent Pipeline for Scientific Research

As the main driving force behind the development of the digital economy, technological innovation is a crucial support for its advancement. Therefore, promoting the construction of technology innovation platforms and building a talent pipeline for scientific research are important aspects of the digital economy's development. Governments should tailor innovation promotion plans according to local conditions, intensify efforts to attract talent and wisdom, and build teams of scientific research personnel to provide strong support for the development of the digital economy.

Technology innovation platforms are crucial for promoting the development of the digital economy. Governments can foster the construction and development of such platforms by increasing investment and support, creating a group of internationally leading technology innovation platforms, and providing strong technical support for the digital economy. Moreover, governments should formulate various preferential policies to attract more outstanding scientific researchers and high-end talent to the development of the digital economy.

(3) Fully Utilize Spatial Spillover Effects to Promote Regional Coordinated Development

The development of the digital economy impacts not only individual regions but also has profound implications for the development of entire regions. With the development and popularization of digital infrastructure, regions with advanced digital economy development can radiate to surrounding areas through positive spatial spillover effects, promoting coordinated regional economic development.

Governments can promote digital infrastructure construction and create hubs for digital infrastructure, attracting more enterprises and high-end talent to foster the development of the digital economy. Additionally, governments should enhance regional digital resource sharing, expand the radius of the digital economy's spillover, fully leverage the dividends of digital economic development, promote the optimization and balanced coordination of regional trade structures, and achieve sustainable development.

Reference

[1] WU Xiaoyi, ZHANG Yajing. An analysis of the status quo and international competitiveness of China's digital economy. Science Research Management, 2020, 41(5): 250 - 258.

[2] Fei Wang, Benhai Guo, Zixing Wang, Yuxin Wu. The impact of digital economy on the export competitiveness of China's manufacturing industry [J]. Mathematical Biosciences and Engineering, 2023, 20(4): 7253-7272.

[3] Chang J, Lan Q, Tang W, Chen H, Liu J, Duan Y. Research on the Impact of Digital Economy on Manufacturing Total Factor Productivity. Sustainability. 2023; 15(7): 5683.

[4] Reza Najarzadeh, Farzad Rahimzadeh, Michael Reed, Does the Internet increase labor productivity? Evidence from a cross-country dynamic panel, Journal of Policy Modeling, Volume 36, Issue 6, 2014, Pages 986-993, ISSN 0161-8938, 2014.10.003.

[5] Kan D, Lyu L, Huang W, Yao W. Digital Economy and the Upgrading of the Global Value Chain of China's Service Industry. Journal of Theoretical and Applied Electronic Commerce Research. 2022; 17(4): 1279-1296.

[6] Guo, Y., & Jiang, F. (2023). How Does the Digital Economy Drive High-Quality Regional Development? New Evidence from China. Evaluation Review, 0(0).

[7] Hausmann, R., Hwang, J. Rodrik, D. What You Export Matters [J]. Journal of Economic Growth, 2007, 12(1): 1-25.

[8] ABELIANSKY L, HILBERT M. Digital Technology and International Trade: Is it the Quantity of Subscriptions or the Quality of Date Speed the Matters? [J]. Telecommunications Policy,2016(1):35-48

[9] Aghion, P., Howitt, P. & Prantl, S. Patent rights, product market reforms, and innovation. J Econ Growth 20, 223–262 (2015).

[10] FREEMAN C, PEREZ C. Technical revolutions and financial capital: The dynamics of bubbles and golden ages [M]. Chel-tenham, UK: Edward Elgar Publishing, 2002: 38-66.

[11] YANG Qingfeng, LI Xiaohua. Study of technological economy paradigm structures, constraint factors and development strategies of booming digital economy [J]. Journal of Hubei University (Philosophy and Social Science),2021,48(1): 126 -136.

[12] Dong, P.; Zhu, Y.; Duan, S.; Wu, M.; Bao, J. How Does the Digital Economy Promote a Culture of Business Innovation? A Study Based on Human Capital Allocation Perspective. Sustainability 2023, 15, 6511.

[13] David J. Teece, Profiting from innovation in the digital economy: Enabling technologies, standards, and licensing models in the wireless world, Research Policy, Volume 47, Issue 8, 2018, Pages 1367-1387, ISSN 0048-7333

[14] Z. Li and Y. Liu, "Research on the Spatial Distribution Pattern and Influencing Factors of Digital Economy Development in China," in IEEE Access, vol. 9, pp. 63094-63106, 2021

[15] Lin Liang, Yan Li, How does government support promote digital economy development in China? The mediating role of regional innovation ecosystem resilience, Technological Forecasting and Social Change, Volume 188, 2023,122328, ISSN 0040-1625

[16] Huang, S.; Ye, W.; Han, F. Does the Digital Economy Promote Industrial Collaboration and Agglomeration? Evidence from 286 Cities in China. Sustainability 2023, 15, 14545.

[17] FISS P C. A set-theoretic approach to organizational con-figurations [J]. Academy of Management Review, 2007, 32(4): 1180-1198.

[18] Hausmann,R., Hwang, J. Rodrik, D. What You Export Matters [J]. Journal of Economic Growth, 2007, 12(1): 1-25.

[19] STUETZER M, AUDRETSC D B, OBSCHONKA M, et al. Entrepreneurship culture, knowledge spillovers, and the growth of regions. Regional Studies, 2018, 52 (5): 603-618.

[20] WANG Jian, ZHANG Chi. Product variety decisions for R&D capability improvement L]. Studies in Science of Science, 2020, 38(11): 2008 -2019.

[21] WEN Jun, YAN Zhijun, CHENG Yu. Digital economy and upgrading regional innovation capacity. Inquiry into Eco-nomic Issues, 2019(11): 112-124.

[22] THORNTON J. Government size and the stability of out put: Evidence from emerging market economies. Applied Eco-nomics Letters, 2010, 17(8): 733-736.

[23] QIU Bin, YIN Wei. Does China's manufacturing exports have domestic market effects?. The Journal of World Econo-my, 2010, 33(7): 44 -63.

[24] RAGIN C C. Redesigning social inquiry: Fuzzy sets and beyond M. Chicago: University of Chicago Press, 2008: 56-78.

[25] Greckhamer, T., Furnari, S., Fiss, P. C., & Aguilera, R.V. (2018). Studying configurations with qualitative comparative analysis: Best practices in strategy and organization research. Strategic Organization, 16(4), 482-495.

[26] FISSPC.A set-theoretic approach to organizational configurations [J]. Academy of Management Review, 2007, 32(4):1180-1198.

[27] SCHNEIDER C Q, WAGEMANN C. Set - theoretic methods for the social science: A guide to qualitative comparative analysis [M]. Cambridge: Cambridge University Press, 2012: 101-148.