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Research on Innovative Measurement of Chinese Urban Digital Economy Development and Its Impact on Enterprise Export Resilience

-- From the Perspective of Material Mechanics

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Abstract: With the widespread application of digital technology, the digital economy has become a new engine for promoting economic development in various countries. However, there are deficiencies in measuring the level of urban digital economy development in China, and the impact of urban digital economy on micro enterprises is still unknown. Therefore, this study aims to provide a scientific and comprehensive method for measuring the level of urban digital economy development, and explore the impact mechanism of urban digital economy development on export resilience from the perspective of trade resilience of export enterprises. Research has found that the construction of indicators for the development level of urban digital economy should coordinate three aspects: digital infrastructure, digital industry, and digital governance; The impact of urban digital economy development on the export resilience of enterprises is mainly achieved through export structure, export diversity, and improving their multi-faceted dynamic capabilities. This study provides a comprehensive measurement method for the development level of urban digital economy and elucidates the relationship between urban digital economy and enterprise export elasticity. It not only provides reference for related research, but also provides inspiration for micro enterprises to apply digital technology to improve export resilience.

Keywords: Digital Economy; Export Resilience; Materials Mechanics; Trade Structure; Dynamic Capability.

1. Introduction

At the main forum of the 2024 Global Digital Economy Conference, the "Global Digital Economy White Paper (2024)" released by the China Academy of Information and Communications Technology shows that in 2023, the total digital economy of five countries including the United States, China, Germany, Japan, and South Korea will exceed $33 trillion, with a year-on-year growth of over 8%; The digital economy accounts for 60% of GDP, an increase of about 8 percentage points compared to 2019, indicating that the digital economy has become a new engine for promoting economic growth in various countries. For China, in recent years, it has attached great importance to the development of the digital economy and elevated it to a national strategy, deploying and promoting the development of the digital economy at the national level. In recent years, China's digital economy has developed rapidly and achieved remarkable results. According to the "China Digital Economy Development Report" released by the China Academy of Information and Communications Technology in 2023, the scale of China's digital economy has grown from 22.6 trillion yuan to 50.2 trillion yuan from 2016 to 2022. But at the same time, we also have to admit that there is still a significant gap between the current development of China's digital economy and the world's digital economy powers and powerhouses. The Chinese digital economy presents the characteristics of being "big but not strong, fast but not excellent". It should also be noted that in the rapid development of China's digital economy, there have been some unhealthy and non-standard signs and trends, which will affect the healthy development of China's digital economy. For example, the report points out that in terms of digital industrialization, China's urban spatial traction model can be summarized as a "one core, three poles, and multiple strengths" pattern. The driving relationship of digital industrialization, with Beijing as the core and Shanghai, Shenzhen, Hangzhou and other growth poles, is more obvious. In terms of industrial digitization, China's urban spatial traction model can be summarized as the "two super, eight extreme, and many strong" pattern. The "two super" refers to cities centered around Beijing and Shanghai, while the "eight poles" refer to cities such as Fuzhou, Dalian, Guangzhou, Chongqing, Xi'an, Shenzhen, Nanjing, and Suzhou. These cities have a strong level of digital industrial development and have a driving effect on surrounding cities. From this, it can be seen that whether it is industrial digitization or digital industrialization, the development of most cities in China lacks initiative and has been in a leading position for a long time. Therefore, it is particularly important to accurately measure the level of digital economic development in these cities, use indicators to let city policy makers understand the level of urban digital economic development, and make proactive adjustments.

The digital economy not only guides economic growth, but also empowers international trade. According to data from the Chinese Ministry of Commerce, the scale of China's digital service trade has continued to expand in recent years. For example, in 2021, China's digital service trade volume reached 2.33 trillion yuan, a year-on-year increase of 14.4%; Among them, the export of digital services reached 1.26 trillion yuan, an increase of 18%. This indicates that digital service trade is becoming an important force driving the growth of China's export trade. Alibaba's cross-border e-commerce platform estimates that in the next 5-10 years, there

will be a growth potential of nearly 1 billion consumers in the overseas e-commerce market, and the growth potential of GMV (Gross Merchandise Volume) can reach 3 trillion to 5.7 trillion US dollars. However, unpredictable external shocks such as the financial crisis, trade frictions and the COVID-19 continue to impact a country's export trade. While the digital economy promotes trade transformation and growth, whether it will enhance export resilience and through what channels, these questions are urgently needed to be answered in current research.

The research objectives of this study are twofold: firstly, to construct a more scientific and comprehensive index for the development of urban digital economy; secondly, to explore the mechanism between the development of urban digital economy and the export resilience of enterprises. This study contributes to the implementation of China's requirements for the development of the digital economy, helping urban planners and policy makers understand the current situation, potential, and shortcomings of urban digital economy development, and make targeted adjustments and reforms. It points out the direction for the vast majority of cities to actively adjust their problems according to measurement indicators, rather than passively relying on the driving force of surrounding super cities. At the same time, it can also help cities establish connections between the development of digital economy and high-quality export trade, promoting comprehensive and sustainable economic development. In theory, this study is a development and supplement to the existing measurement methods and indicators, which helps researchers choose more accurate indicators. At the same time, it also helps to enrich the academic research on the relationship between the digital economy, international trade, and export resilience.

2. Literature Review

In current research, there are many literature and diverse methods studying the level of digital economy development at the provincial level. For example, Li and Wang (2023) divided the benchmark layer into innovation, coordination, openness, greenness, and sharing when measuring the level of China's digital economy development, using the TOPSIS method to measure the level of digital economy development [1]. Xu and Liu (2023) selected digital infrastructure, digital innovation capability, digital coverage breadth, digital industry development, and government support as secondary indicators, and based on this, selected tertiary indicators to measure the level of provincial digital economy development using entropy method[2]. Shengand Liu (2022) [3] believe that the current measurement of the digital economy is mainly divided into research on national economic accounting methods (Guan et al., 2020) [4], measurement of digital economy value added (China Academy of Information and Communications Technology, 2019), construction of satellite accounts (OECD, 2017), and index compilation (Zhang & Jiao, 2017) [5]. However, due to the exploratory stage of research, the measurement results vary greatly, and most scholars are studying the level of digital economy development at the provincial level rather than the city level. Although OECD, UNCTAD, and the European Union have published measurement indicators and methods for the digital economy internationally, they are limited to the national level and do not consider China's provincial level, let alone contribute to the measurement of digital economy development at the city level. Therefore, building a measurement system for urban digital economy development needs to be reconsidered.

In the research on the impact of the digital economy on export trade, some scholars have long paid attention to the impact of the Internet on national trade behavior, Shen and Yuan (2020) [6] believe that the development of the Internet and ICT can reduce trade costs, thus promoting the growth of import and export trade (Dennis&Shepherd, 2011 [7]; Hendy&Zaki, 2021 [8]). Some scholars also believe that the digital economy can enhance the technological complexity of manufacturing exports through channels such as transaction costs (Du & Guan, 2021 [9]) and industrial structure (Yao, 2021 [10]). In addition, the development of the digital economy also helps to increase the domestic value-added rate of exports (Cortes et al., 2017 [11]). Under the external impact, Albertos et al. (2014) [12] found that the export of enterprises with high information technology intensity and high Internet embeddedness was not affected by the international financial crisis. The empirical results of Ma et al. (2023) show that the development of the digital economy has a significant promoting effect on enhancing regional export resilience. The promoting effect of improving digital infrastructure and good digital innovation capabilities is more significant. In addition, the digital economy can improve regional export resilience through innovation effects, and good infrastructure and marketization level can strengthen this promoting effect [13]. Su & Lu (2023) also found that the development of digital economy helps to enhance the export resilience of cities. The mechanism analysis shows that the development of digital economy mainly enhances the export resilience of cities by reducing trade costs, improving innovation capabilities, and enhancing entrepreneurial vitality. Li et al. (2023) believe that the development of the digital economy has enhanced the resilience of a country's export trade, and innovation and production capabilities are the two channels through which the digital economy affects the resilience of export trade. In summary, the development of the digital economy will empower international trade and promote the improvement of regional export resilience. However, no scholar has yet answered how urban digital economy development can promote the improvement of enterprise export resilience.

3. Measurement Methods for Urban Digital Economy

Based on previous research, this study believes that measuring the level of digital economic development in a city must be done from the perspectives of digital infrastructure, digital industries, and digital governance. According to the measurement method of the provincial digital economy development index proposed by Sheng & Liu (2022), the first level indicators of digital infrastructure and digital governance are introduced. The indicator system for digital infrastructure is constructed as follows:

Table 1. Construction of Indicator System for Digital Infrastructure

First level indicator	Second level indicators	Third level indicators
Digital infrastructure	Digital Physical Infrastructure	Number of IPV4 addresses
		Number of websites
		Number of Domain Names
		Internet broadband access density
		Density of long-distance optical cable lines
		Capacity of local telephone exchange
		Capacity of mobile telephone exchange
	Digital Knowledge Capital	The proportion of employees in the information transmission, software, and information technology service industries to the total number of employees in urban units
		Per capita years of education
		Per capita education expenditure

Next, the indicator system for digital governance will be constructed as follows:

Table 2. Construction of Digital Governance Indicator System

Digital governance	Personal digital governance	Computer ownership per 100 households
		Mobile phone ownership per 100 households
		Internet penetration rate (number of Internet users/total number of permanent residents)
		Mobile phone penetration rate
	Enterprise Digital Governance	Industrial robot installation density
		Number of manufacturing enterprises in the electronic information industry
		Number of software and information technology service industry enterprises
	Government digital governance	Internet Governance Index
		Government Information Disclosure Index
		Online Interaction Index between Government and Citizens
		Online Service Index

Regarding the measurement of the digital industry, as there is no convincing index system for measuring the digitalization of industries both domestically and internationally, the measurement indicators and weighting methods proposed by Lin (2023) are as follows:

Table 3. Construction of Digital Industry Indicator System

System	First level indicator	Second level indicators
Digital industry	Industrial digitalization investment	Full time equivalent R&D personnel of industrial enterprises above designated size
		Number of computers per 100 employees in a company
		R&D expenditure as a percentage of GDP
	Industrial digitalization capability	E-commerce sales revenue
		Sales revenue of software business
		Number of enterprise e-commerce transactions
	Industrial digitalization application	Number of employees in the software industry
		Number of people using computers
		Number of websites per hundred enterprises

Finally, this study determined a more comprehensive method for measuring the level of urban digital economy development, with specific indicators and weight divisions as follows:

Table 4. Index System of the Development Level of Urban Digital Economy

Target layer	Criteria layer	Sub-criteria layer
Digital Economy Development Index	Digital infrastructure (25%)	Digital material infrastructure (80%), digital knowledge capital (20%)
	Digital industry (50%)	Industrial digitalization investment (25%), industrial digitalization capability (25%), industrial digitalization application (50%)
	Digital governance (25%)	Personal digital governance (40%), enterprise digital governance (40%), government digital governance (20%)

The above indicators and weights are considered suitable for the current development status of China's urban digital economy in this study. Other countries should adjust the measurement of urban digital economy development level

based on their own characteristics or digital economy development level in detail. However, digital infrastructure, digital industries, and digital governance should be the core parts of constructing the indicator system.

4. Discussion on the Mechanism of the Impact of Urban Digital Economy on Enterprise Export Resilience

According to Liu (2024), export resilience should be measured and analyzed from the perspective of material mechanics. Export resilience should be defined as the ability of an enterprise or region to resist and recover from external shocks, as well as its ability to transform and improve after shocks[17]. Based on its research perspective of combining material mechanics theory with international trade facts, this study will explore the mechanism of how urban digital economy development enhances enterprise export resilience in this section.

4.1. Optimize the export structure of enterprises

In materials mechanics, the toughness of a material depends to some extent on its composition, that is, what atoms or molecules make up the material. An example is that, under the same specifications and manufacturing process, the toughness of iron plate is much higher than that of aluminum plate. Extending this fact to the field of export trade, a company's export resilience should depend on what products make up its exports. Suppose that the export products of an enterprise are mainly composed of physical products such as furniture and electrical appliances. Under the COVID-19 epidemic, the export of these products will be subject to layer upon layer detection, and even some countries chose to temporarily close at that time. Therefore, the enterprises whose exports are composed of physical products have been greatly hit by external shocks, and their export resilience is poor. This study suggests that the development of the digital economy can change the export product structure of enterprises, greatly improving the digitalization level of export products. This can not only improve efficiency, but also significantly reduce the impact of external shocks on highly digitized export products. For example, under the COVID-19 epidemic, if an enterprise's export products are mainly composed of data or online services, the impact of external shocks can be said to be minimal.

4.2. Enhancing the Relevance of Enterprise Exports

In material mechanics, in addition to the molecules or atoms that make up the material, the toughness of the material is also affected by the manufacturing process. Materials with uniform texture have stronger toughness. On a microscopic level, the higher the degree of bonding between the molecules or atoms of the material, the stronger the toughness of the material. For example, assuming there are two iron plates, the iron plate with uniform texture and good bonding between molecules or atoms has stronger toughness. This requires not the density of the iron plates, but the degree of correlation between microscopic molecules or atoms. When applied to the field of export trade, it is often believed that diversification is a key strategy to improve export resilience, but this is not the case. If a company only emphasizes the diversification of export products or export markets, it will face more uncertainty and may not necessarily improve its export resilience. Therefore, what truly improves its export resilience performance is related diversification, which means that there is a certain correlation between the various products exported by the enterprise. This specialized export makes the enterprise more resistant to external shocks. For example, enterprise A exports three types of products, food, clothing and auto parts. Under the COVID-19 epidemic, the three types of products have poor relevance, and their R&D, production and sales resources are relatively independent, so their exports are vulnerable to external shocks. The three types of products exported by Company B are all automotive parts. Therefore, under external shocks, their resources can be shared, resulting in higher efficiency in each link. The expansion effect of their brand enhances their ability to resist risks, and thus their resilience is stronger. However, it should be noted that excessive diversity means that 'all eggs are in one basket', and once faced with larger or targeted external shocks, the losses may be devastating. For example, if there is a trade friction between the country where Company B is located and a certain country, and all automobile parts are banned from import, then Company B's exports to that country will become zero. Therefore, the key lies in the appropriate balance between correlation and diversity. This study suggests that the development of the digital economy can enhance the relevance and diversity of export products through the integration of digital technologies, thereby improving the export resilience of enterprises. The digital economy has promoted deep integration and collaborative development between different industries. This integration application not only helps enterprises reduce production costs and improve production efficiency, but also helps them develop more related products with differentiated competitive advantages, improve the relevance and market competitiveness of export products. At the same time, the digital economy can also empower enterprises to better meet the diverse needs of the international market. Enterprises export a wider range of products and target more importing countries.

4.3. Developing dynamic capabilities of enterprises

In materials mechanics, the toughness of materials is not only influenced by the manufacturing process and the structure of the constituent materials, which are considered internal factors that affect the toughness of materials. Of course, external factors can also affect the toughness of materials. The most common factor is temperature. Generally speaking, the higher the temperature, the stronger the toughness of the material, and the lower the temperature, the worse the toughness of the material. A famous example is the Titanic, whose hull was made of steel plates. Colliding with an iceberg would not have caused such serious consequences, but the iceberg lowered the temperature of the seawater, thereby weakening the toughness of the hull, which led to the fracture of the Titanic. In fact, temperature changes alter the structure of materials and the degree of bonding between molecular atoms, which in turn affects toughness. Expanding into the field of export trade, the adjustment of a company's export products and their relevance can certainly change its resilience performance. The ability of enterprises to actively change their export structure, relevance, and diversity is considered a reflection of dynamic capabilities. This study suggests that the development of the digital economy in the

region where the enterprise is located can enhance the dynamic capabilities of the enterprise. According to the theory of dynamic capability, dynamic capability mainly includes three dimensions: the ability to perceive the market, the ability to utilize resources, and the ability to innovate. The development of the digital economy has first improved the ability of enterprises to perceive changes in the international market. For example, the use of the Internet has made enterprises more aware of the needs of overseas markets, more efficient and accurate information acquisition, and enterprises can take the initiative to identify opportunities and risks and make adjustments in exports. Secondly, the development of the digital economy has made the supply chain turnover of the entire industry more efficient, improving the ability of enterprises to utilize resources. For example, IoT technology helps companies monitor inventory in real-time, big data technology optimizes storage layout and paths, artificial intelligence improves automation and intelligence levels, and digital technology greatly enhances the ability of companies to utilize and integrate resources. Finally, the development of the digital economy has brought about an increase in the innovation capabilities of enterprises. Enterprises can apply technologies such as artificial intelligence, blockchain, and big data to empower various aspects of research and development, production, and marketing, and enhance innovation output. In summary, this study believes that the development of the digital economy brings about an improvement in the dynamic capabilities of export enterprises, and the ability of enterprises to actively adjust their exports is also an important source of their export resilience.

5. Conclusion

This study combines the current research status to construct a more comprehensive and scientific indicator system for measuring the development level of urban digital economy. The indicator system takes digital infrastructure, digital industry, and digital governance as the core aspects for measuring the development of digital economy. In addition, based on the perspective of material mechanics, this study analyzed the impact mechanism of digital economy development on the export resilience of enterprises, and believed that the improvement of export resilience promoted by digital economy comes from three aspects: export structure, the balance between export relevance and export diversity, and the enhancement of enterprise dynamic capabilities. In future research, relevant researchers can conduct empirical studies based on the measurement method of digital economy development level provided in this article, or analyze the relationship between digital economy and enterprise export resilience from an empirical perspective, and examine the applicability of the three mechanisms provided in this study.

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