Measurement and Analysis of the Digital Economy from the Perspective of High-Quality Development

-- Taking Liaoning Province as an Example

Yi Xiong*

School of Economics, Liaoning University, Shenyang, Liaoning 110100, China

*xy2006-10@qq.com

Abstract

Currently, the digital economy has become a new driving force for economic growth, laying an important foundation for high-quality development. Therefore, this study uses an entropy-coupling model to analyze the development of the digital economy in Liaoning Province from 2019 to 2023. The analysis reveals that, under the framework of high-quality development, the level of digital economy development in Liaoning Province continued to improve from 2019 to 2023. This growth is the result of the synergistic drive of policy guidance, industrial upgrading, and social demand, with its driving mechanism shifting from relying on investment to relying on integrated applications. Specifically, progress has been made in the three subsystems of financial research, information interaction, and social development, jointly promoting the growth of the digital economy. Furthermore, the interaction between internal systems has evolved from severe imbalance to high-quality coordination, indicating that Liaoning Province's digital economy has built a deeply integrated new development ecosystem and entered a new stage of high-quality and sustainable development.

Keywords

Digital economy, high-quality development, Liaoning Province, entropy-coupling model.

1. Introduction

The concept of the "digital economy" was first proposed in the mid-1990s and, after being further promoted by various international organizations, has become a focus of global economic policy. China has accurately grasped international trends and elevated the development of the digital economy to a national strategy. In 2024, the added value of my country's core digital economy industries accounted for approximately 10% of GDP, and the scale of China's digital economy remained the second largest in the world. In 2017, the 19th National Congress of the Communist Party of China declared that my country's economy had entered a stage of high-quality development, which is of great significance for achieving sustainable growth and improving people's well-being. As a crucial engine for promoting high-quality development, exploring the development of the digital economy can effectively help break through economic growth bottlenecks and build new competitive advantages.

At present, different scholars have conducted diverse analyses and studies on the digital economy. In terms of methodological exploration, Zhao Tao et al[1] . used various methods such as DID to study the impact and mechanism of the digital economy on the high-quality development of cities, and found that the digital economy has a significant promoting effect on high-quality development; Zhang Xun et al. [2] used the dimensionless method of indicators and the instrumental variable estimation method to conclude that the development of digital finance is conducive to China's inclusive growth; He Fan and Liu Hongxia [3] used the

instrumental variable method and the lag regression method to evaluate the performance improvement effect and realization path of enterprise digital transformation, and found that digital transformation significantly improves the economic benefits of real enterprises. Regarding the construction of the indicator system, Liu Jun et al [4] . proposed to use the informatization development indicator, the Internet development indicator and the digital transaction development indicator as its evaluation system in the study on the measurement and driving factors of China's digital economy. Wang Jun et al[5]. used the first-level indicators such as the carrier of digital economic development and digital industrialization to study the development level and evolution measurement of China's digital economy. Xu Xianchun and Zhang Meihui [6] studied the scale of China's digital economy by measuring the scale of indicators such as the added value of the digital economy and the total output of the digital economy.

In summary, current research on the digital economy largely focuses on its macro-level measurement and its driving mechanism for high-quality development. While the scope of research varies, it suffers from timeliness limitations due to a lack of consideration for technological advancements and business model innovation, and a lack of differentiated research by not focusing on specific regions. Therefore, this study utilizes an entropy-coupling model to conduct a measurement analysis of the digital economy in Liaoning Province from the perspective of high-quality development. The aim is to reveal the key driving factors for the further development of Liaoning's digital economy, address the shortcomings of existing research in terms of regionality and timeliness, and ultimately formulate targeted policy recommendations, providing empirical evidence for the digital transformation of the old industrial base in Northeast China.

2. Research Methods, Regions, Data, and Framework

2.1. Research Methods

This study employs quantitative analysis methods. To better analyze the development of the digital economy in Liaoning Province, the existing and mature "entropy-coupling" model is used for analysis.

2.1.1. Entropy Method

The entropy method is an objective weighting method that can largely eliminate biases caused by subjective factors. The specific calculation steps are as follows:

(1) Data standardization: Assume that the data of Liaoning Province in t each year ($t = 1,2,\dots,T$) within are analyzed, and the number of indicators is n, X_{ij} which represents i the standardized value of the indicator ($j = 1,2,\dots,n$) in ($i = 1,2,\dots,T$) the period, $maxx_{ij}$ and $minx_{ij}$ are j the maximum and minimum values of the indicator in all periods, T respectively j. To avoid zero values, the standardized data are shifted by 0.0001.

Positive indicators (the higher the value, the better):

$$X_{ij} = \frac{x_{ij} - minx_j}{maxx_j - minx_j} + 0.0001 \quad (1)$$

Negative indicators (the smaller the value, the better):

$$X_{ij} = \frac{max_{ij} - x_{ij}}{maxx_j - minx_j} + 0.0001 \quad (2)$$

(2) Calculate the proportion of the i-th i period j under the i-th indicator:

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{T} x_{ij}} \tag{3}$$

(3) Calculate $j$the entropy value of the i-th index:

$$e_j = -k \sum_{i=1}^{T} p_{ij} \ln(p_{ij}), \text{where } k = \frac{1}{\ln T} \tag{4}$$

(4) Calculate $j$the coefficient of variation of the i-th indicator:

$$g_j = 1 - e_j \tag{5}$$

(5) Calculate $j$the weight of the i-th indicator:

$$w_j = \frac{g_j}{\sum_{j=1}^{n} g_j} \tag{6}$$

(6) Calculate $i$the overall development level score for each period:

$$S_i = \sum_{j=1}^{n} w_j \times p_{ij} \tag{7}$$

2.1.2. Coupled Coordination Model

The coupling coordination degree model can be used to measure the degree of interaction and coordinated development of different subsystems within the digital economy of a research area. The calculation steps are as follows: Assume that two subsystems A and B are defined, and their comprehensive development levels are $U_A$and respectively U_B(the weights of each subsystem and their comprehensive scores can be calculated using the entropy method described above).

Coupling degree calculation: Coupling degree reflects the strength of the interaction between subsystems. The formula is:

$$C = \left[\frac{U_A \times U_B}{\left(\frac{U_A + U_B}{2} \right)^2} \right]^{\frac{1}{2}} \tag{8}$$

Among them, $C \in [0,1]$the closer the value of is to 1, the stronger the coupling effect between subsystems.C

Coupling coordination degree calculation: To more accurately reflect the level of coordinated development among subsystems, a coupling coordination degree is introduced. Its formula is:

$$D = \sqrt{C \times T}, T = \alpha U_A + \beta U_B \tag{9}$$

In the formula, D is the coupling coordination degree, T is the subsystem comprehensive coordination index, and α and β are the subsystem weights (according to the actual focus of the study, if the two subsystems are equally important, α=β=0.5 can be taken; if the weights of the two subsystems are different, the weights obtained after processing by the entropy method shall be used); $D \in [0,1]$ the D larger the value of, the better the coupling coordination development between the subsystems. The coupling coordination level can be divided

according to the D value (for example, 0.9-1.0 is excellent coordination, 0.7-0.8 is medium coordination, etc.) [7] , so as to analyze the coupling coordination situation of the digital economy system in Liaoning Province and related systems.

2.2. Regional Analysis and Data Sources

Liaoning Province, located in the southern part of Northeast China, is the only coastal province in the region, boasting significant geographical advantages. It possesses a strong industrial base and is a core force driving the revitalization of Northeast China. Against the backdrop of high-quality economic development, Liaoning Province continues to optimize and upgrade its industrial structure, focusing on cultivating emerging industries, steadily developing social undertakings, actively practicing the concept of green development, and synergistically promoting ecological environment improvement and sustainable economic and social development. The data in this study comes from the Liaoning Provincial Statistical Yearbook and Social Development Bulletin. For some missing data, linear regression was used to supplement them.

2.3. Research Design

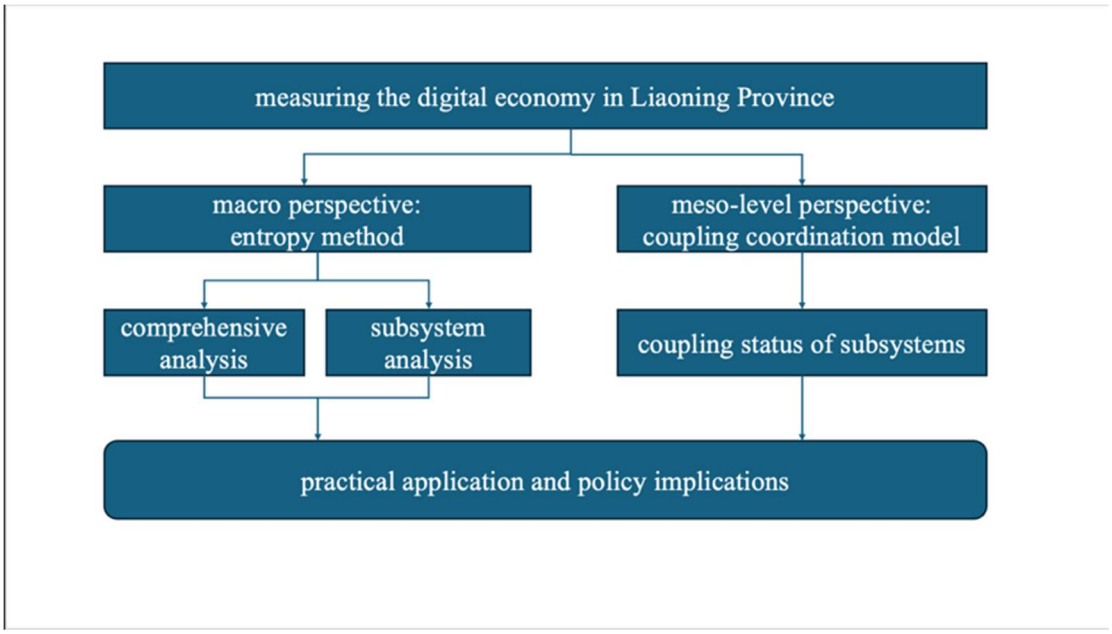


Fig. 1 Study Design Diagram

3. Research and Analysis

3.1. Indicator System

Based on existing research frameworks and a high-quality development perspective, this study proposes that the development of the digital economy should take into account technological drive, factor integration, and social benefits. Furthermore, based on the scientific, rational, and differentiated characteristics of the comprehensive indicator system, a three-dimensional evaluation indicator system for measuring the digital economy of Liaoning Province is developed, encompassing financial research, information interaction, and social development. Substituting the data into formulas (1)-(6) yields the specific weights, as shown in Table 1.

Table 1. Liaoning Province Digital Economy Measurement Index System (2019-2023)

Primary Indicator (U)	Level 3 Indicators	Unit	Weight	Indicator Attributes
U1: Financial Research	X1 Internet broadband access users	Wanhu	5.84%	positive
	X2 Number of employees in the information transmission, software and information technology services industry	10,000 people	9.19%	positive
	X3 Technology Research and Development Expenditure	100 million yuan	5.59%	positive
	X4 Financial Industry Value Added	100 million yuan	4.75%	positive
	X5 e-commerce sales	100 million yuan	9.83%	positive
U2: Information Interaction	F1 Technical Trading Activity	%	7.76%	positive
	F2 Express Volume	10,000 pieces	5.57%	positive
	F3 Number of patent applications from industrial enterprises above designated size	Item	4.27%	positive
	F4 Integrated Circuit Production	10,000 blocks	5.60%	positive
	F5 Mobile Phone Penetration Rate	Department/Person	6.83%	positive
U3: Social Development	W1 per capita disposable income of residents	Yuan	6.45%	positive
	W2 GDP per capita	Yuan	8.17%	positive
	W3 Total retail sales of consumer goods	100 million yuan	4.89%	positive
	W4 GDP of the tertiary industry	100 million yuan	8.12%	positive
	W5 Fiscal Science and Technology Expenditure	100 million yuan	7.13%	positive

3.2. Comprehensive Analysis and Subsystem Analysis

3.2.1. Comprehensive Analysis

Substituting the data into formulas (1)-(7) yields the specific comprehensive development level score, as shown in Fig 2.

Overall, Liaoning Province's comprehensive development level score for the digital economy showed an upward trend from 2019 to 2023. This can be attributed to several factors. First, the policy system has become increasingly perfected and comprehensive. In 2021, Liaoning Province issued the "Digital Liaoning Development Plan," emphasizing the development of an integrated and innovative digital economy. In 2022, the government introduced "Several Measures of Liaoning Province to Accelerate the Development of Core Digital Economy Industries," promoting the rapid development of the digital economy through financial support and other means. Second, industrial transformation has progressed steadily. In 2022, Dalian's cross-border e-commerce import and export transaction volume increased by 309.19% year-on-year, and in 2023, Ansteel Group completed the intelligent transformation of 41 production lines, demonstrating the ongoing digitalization of the manufacturing industry. Simultaneously, social demand has continued to increase.

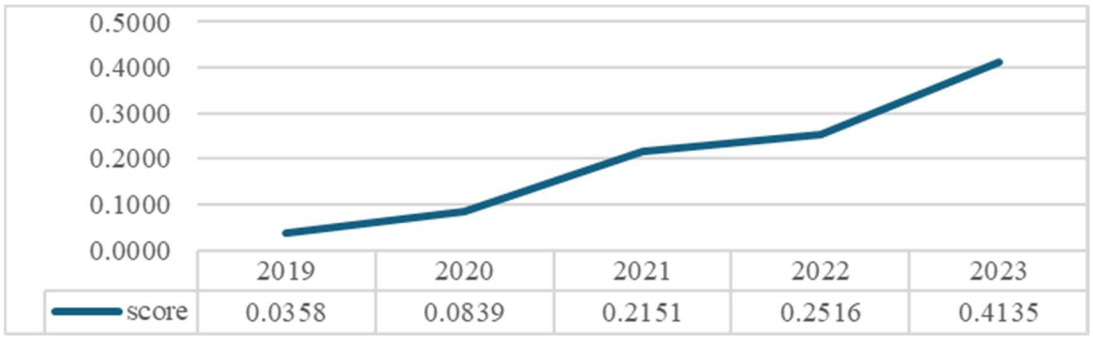


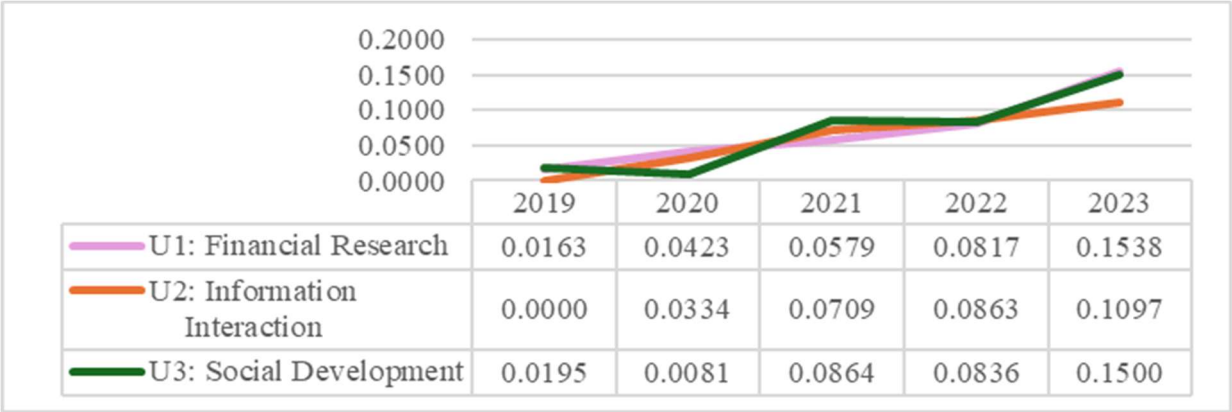
Fig. 2 Comprehensive Development Level Score of Digital Economy in Liaoning Province (2019-2023)

However, the speed of digital economy development varies across different periods. The study divides the overall development of the digital economy from 2019 to 2023 into four stages. In 2020-2021, the overall development level of the digital economy improved rapidly, which was related to factors such as the pandemic accelerating the digital transformation of society and the inclusion of new infrastructure in government performance evaluation targets. 2022-2023 also saw rapid growth in the level of digital economy development. The key tasks outlined in the "Key Points of Digital Liaoning Construction in 2022" and the strategic supporting role of new infrastructure such as the new generation of artificial intelligence public computing power open innovation platform were important driving forces for the development of the digital economy. In contrast, the slow development of Liaoning Province's digital economy in 2019-2020 was due to the fact that large-scale digital transformation had not yet been fully rolled out, and policies mainly focused on top-level design; new infrastructure was still in its early stages of construction, and investment had not yet been transformed into productivity to support industrial upgrading; in 2021-2022, the development of the digital economy was constrained by factors such as the basic completion of shallow digital transformation that was easy to achieve in the early stages, the soaring difficulty and cost of deep transformation such as full-process reengineering, the existence of a "digital divide" between large leading enterprises and upstream and downstream small and medium-sized supporting enterprises, and the fact that large-scale fiscal funds had not yet been transformed into specific projects.

3.2.2. Subsystem Analysis

Substituting the data into formulas (1)-(7) yields the specific development level scores for each subsystem, as shown in Fig 3.

Overall, from 2019 to 2023, the score of Liaoning Province's digital economy subsystem showed an upward trend, for the following reasons. Firstly, precise financial capital support for R&D investment has propelled the digital economy to a new level. The "14th Five-Year Plan" for digital economy development was released in 2021, providing support for goals such as industrial digital transformation through increased financial support. Secondly, information interaction has empowered industrial development, bringing new growth opportunities. Industrial digitalization has shifted from "point-based pilot projects" to "chain-based collaboration." Benchmark projects such as Ansteel's smart steelmaking and BMW Brilliance's 5G fully connected factory have driven the digital collaborative transformation of the industrial chain. Simultaneously, new business models such as e-commerce live streaming and smart logistics have formed clusters, creating a huge endogenous market, and the digital economy has widely penetrated social life.



	2019	2020	2021	2022	2023
U1: Financial Research	0.0163	0.0423	0.0579	0.0817	0.1538
U2: Information Interaction	0.0000	0.0334	0.0709	0.0863	0.1097
U3: Social Development	0.0195	0.0081	0.0864	0.0836	0.1500

Fig. 3 Scores of Liaoning Province's Digital Economy Subsystems (2019-2023)

The financial research system (U1), the overall development score shows an upward trend, with the growth rate gradually accelerating. This can be attributed to the following factors: First, the policy support system is continuously strengthening, with the provincial level issuing numerous special policies for science and technology finance, and government-guided funds totaling nearly 60 billion yuan, providing "patient capital" for innovation. Second, positive feedback from the capital market has boosted external confidence. Since 2019, Liaoning's hard-tech companies, represented by semiconductors, have successively gone public, and venture capital institutions have reaped returns, thereby enhancing the investment confidence of financial capital.

Information interaction systems (U2), the overall development score shows an upward trend, but the growth rate is gradually slowing down. This is because the early development phase from 2019 to 2021 focused on the rapid expansion of new infrastructure, directly driving a rapid increase in the level of digital economy development. In the later development phase from 2021 to 2023, the driving force of digital economic growth shifted from network construction to deeper applications such as network usage. The digital economy began to gradually integrate deeply with the real economy, resulting in slower results and a gradual slowdown in the growth rate of the digital economy.

Social development system (U3), its development score shows an upward trend amid fluctuations. This is mainly influenced by the following factors: First, as the breadth and depth of digital services continue to expand, the complexity of platform data governance gradually emerges, requiring phased adjustments. Second, the COVID-19 pandemic amplified the vulnerability of digital systems in the short term, causing fluctuations in the development score, but it also forced society to optimize its digital service capabilities, generating an extraordinary acceleration effect on the development of the digital economy.

3.3. Coupling Analysis

Substituting the comprehensive development level scores of each subsystem into formulas (8)-(9), we can obtain the coupling degree (C value), comprehensive coordination index (T value), and coupling coordination degree (D value) between subsystems. Based on the coupling coordination degree, we can classify the coupling coordination level and analyze the coupling coordination situation within the system. Specific results are shown in Tables 2 to 5.

Overall, it can be observed that the coordination between the three subsystems shifted from imbalance in 2019-2020 to coordinated development in 2021-2023. A detailed analysis follows.

Table 2. Coupling and Coordination Status of Financial Research and Information Interaction Subsystems (2019-2023)

Year	Coupling Degree C	T value	D value	Coupling Coordination Level	Coupling And Coordination Status
2019	1.000	0.010	0.100	2	Severe disorder
2020	0.974	0.252	0.495	5	On the verge of disorder
2021	0.935	0.475	0.666	7	Primary Coordination
2022	0.970	0.629	0.781	8	Intermediate Coordination
2023	1.000	0.990	0.995	10	High-quality coordination

Table 3. Coupling and Coordination Status of Financial Scientific Research and Social Development Subsystems (2019-2023)

Year	Coupling Degree C	T value	D value	Coupling Coordination Level	Coupling And Coordination Status
2019	0.604	0.049	0.172	2	Severe disorder
2020	0.431	0.103	0.21	3	Moderate disorder
2021	0.958	0.428	0.641	7	Primary Coordination
2022	0.998	0.504	0.709	8	Intermediate Coordination
2023	1	0.99	0.995	10	High-quality coordination

Table 4. Coupling and Coordination Status of Information Interaction and Social Development Subsystems (2019-2023)

Year	Coupling Degree C	T value	D value	Coupling Coordination Level	Coupling And Coordination Status
2019	0.604	0.049	0.172	2	Severe disorder
2020	0.349	0.159	0.236	3	Moderate disorder
2021	0.997	0.597	0.771	8	Intermediate Coordination
2022	0.982	0.656	0.803	9	Good coordination
2023	1.000	0.99 0	0.995	10	High-quality coordination

Table 5. Evolution Analysis of Coupling and Coordination Degree of Digital Economy Subsystems in Liaoning Province (2019-2023)

Year	Financial Research - Information Exchange	Financial Research - Social Development	Information Interaction - Social Development
2019	Severe disorder	Severe disorder	Severe disorder
2020	On the verge of disorder	Moderate disorder	Moderate disorder
2021	Primary Coordination	Primary Coordination	Intermediate Coordination
2022	Intermediate Coordination	Intermediate Coordination	Good coordination
2023	High-quality coordination	High-quality coordination	High-quality coordination

In 2019, the three subsystems of financial research, information exchange, and social development were all severely imbalanced, operating independently and failing to form an efficient interactive system. This was due to several factors: the financial research system was still in the development and testing phase, with cutting-edge technologies such as 5G and artificial intelligence not yet commercially available on a large scale; digital technology innovation was far removed from market demand and had low accessibility; and the coverage of new infrastructure was low, resulting in insufficient impetus for social development.

In 2020, the coordination between subsystems improved somewhat, but remained imbalanced. The coordination between financial research and information exchange was the best, largely due to the COVID-19 pandemic, which forced the rapid integration of financial research and information infrastructure. While advancements in financial research could have boosted business development, delays in demand transmission and application implementation resulted in continued imbalance between the two. The explosive growth in digitalization

demand during a specific period placed immense pressure on new infrastructure development in the short term, leading to an imbalance between supply and demand and further disrupting the flow of information and societal development.

In 2021, the relationships between subsystems entered a coordination phase, with positive interactions beginning to occur. Multiple top-level design policies were fully implemented, the connection between technological research and development and practical application became closer, and digital industrialization and industrial digitalization were promoted in synergy. Simultaneously, due to the near completion of new infrastructure construction and the stable and continuous demand for digital services generated by the pandemic, the coordination between the information interaction and social development subsystems developed well. However, the practical application of financial research technologies to information interaction to promote social development required a certain amount of time, thus the coordination between subsystems developed more slowly. This trend continued in 2022, with the information interaction and social development subsystems entering a good coordination phase first, demonstrating the most direct empowering role of information interaction in social development.

In 2023, all subsystems achieved optimal coordination, and a mature and advanced digital economy ecosystem was initially established. A virtuous cycle of self-reinforcement was formed between the systems: cutting-edge technologies from financial research were transformed into inclusive services through the information exchange system, enabling society to develop through the application of technology and generate demands and feedback for financial research. These three elements are nested and mutually reinforcing, constituting the core driving force for the growth of the digital economy.

4. Conclusion and Discussion

This study primarily found that, from a high-quality development perspective, the overall development level of Liaoning Province's digital economy showed an upward trend from 2019 to 2023. Overall, the rise in Liaoning's digital economy development level is the result of the combined effects of policy layout, industrial transformation, and social demand, reflecting a shift from investment-driven growth to application-driven growth. Secondly, the three subsystems of financial research, information interaction, and social development all achieved significant development, although their paths and pace differed, collectively constituting the core engines of digital economy development. Simultaneously, the coupling and coordination relationships between subsystems have achieved a leap from severe imbalance to high-quality coordination, marking Liaoning Province's digital economy entering a high-quality development stage of system integration and virtuous cycle.

The digital economy in Liaoning Province will exhibit characteristics of endogenous growth and deep integration with social life in its later stages, thus it can be extended towards "data valorization" and "digital inclusion." Furthermore, with technological development, the formation of new productive forces, and the improvement of industrial integration policies, future research should focus more on incorporating core indicators of new productive forces for measurement and analysis. The limitations of this study lie mainly in the relatively singular research methodology used and the lack of practical application, indicating insufficient attention to practicality.

References

[1] Zhao Tao, Zhang Zhi, Liang Shangkun. Digital Economy, Entrepreneurial Activity and High-Quality Development: Empirical Evidence from Chinese Cities [J/OL]. Management World, 2020, 36(10): 65-76. DOI:10.19744/j.cnki.11-1235/f.2020.0154.

[2] Zhang Xun, Wan Guanghua, Zhang Jiajia, et al. Digital Economy, Inclusive Finance and Inclusive Growth [J]. Economic Research, 2019, 54(8): 71-86.

[3] He Fan, Liu Hongxia. Evaluation of the performance improvement effect of digital transformation of real economy enterprises from the perspective of digital economy [J]. Reform, 2019(4): 137-148.

[4] Liu Jun, Yang Yuanjun, Zhang Sanfeng. Research on Measurement and Driving Factors of China's Digital Economy [J/OL]. Shanghai Economic Research, 2020(6): 81-96. DOI:10.19626/j.cnki.cn31-1163/f.2020.06.008.

[5] Wang Jun, Zhu Jie, Luo Xi. The Development Level and Evolution Measurement of China's Digital Economy [J/OL]. Quantitative Economics and Technological Economics Research, 2021, 38(7): 26-42. DOI:10.13653/j.cnki.jqte.2021.07.002.

[6] Xu Xianchun, Zhang Meihui. Research on the Measurement of China's Digital Economy Scale - Based on the Perspective of International Comparison [J/OL]. China Industrial Economics, 2020(5): 23-41. DOI:10.19581/j.cnki.ciejournal.2020.05.013.

[7] Sun Yu, Cui Yin, Feng Yanchao. Evaluation of the coordinated development of economic, social and environmental benefits of urban public transportation infrastructure [J]. Economic and Management Review, 2019, 35(06): 122-135. DOI: 10.13962/j.cnki.37-1486/f.2019.06.012