



Research on the Coordinated Development of Urban Digital Economy Based on the “Entropy Weight-Coupling Coordination Model” —— Taking Beijing-Tianjin-Hebei as an Example

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Abstract. Against the background of the national “14th Five-Year Plan” to promote the construction of Digital China, this study analyzes the synergy of digital economic development in the Beijing-Tianjin-Hebei region from 2019 to 2023 based on the entropy method and coupling coordination model. The results show that Beijing’s digital economy comprehensive score and coupling coordination degree are significantly higher than those of Tianjin and Hebei, reflecting its core advantages in technological innovation and resource agglomeration. The study found that the coordination capacity of the digital economy in Beijing-Tianjin-Hebei has been decreasing year by year, which may be related to factors such as the widening regional gap caused by Beijing’s “siphon effect”, the weak digital infrastructure in Tianjin and Hebei, and the insufficient capacity of industrial acceptance. In order to improve the regional coordination efficiency, it is necessary to strengthen the technology spillover and resource sharing mechanism between Beijing and Tianjin and Hebei, focus on improving the layout of digital infrastructure in Tianjin and Hebei, optimize the adaptability of industrial acceptance policies, and pay attention to the driving role of differentiated factors such as science and technology investment and government governance on regional coordination. The research conclusion provides a recent dynamic reference for the coordinated governance of the digital economy in Beijing-Tianjin-Hebei, and the trend drivers can be further analyzed in combination with policy practice in the future.

Keywords: Digital Economy, Industrial Upgrading, Entropy Method, Coupling Coordination Analysis

1 Introduction

Under the strategic framework of the country’s “14th Five-Year Plan” to comprehensively promote the construction of Digital China, the digital economy has become an important engine driving regional coordinated development. As a major national strategic layout region, the quality of digital economic development in Beijing- Tianjin-

Hebei is directly related to the effectiveness of cultivating new quality productivity^[1]. Research shows that digital technology plays a dual role: it accelerates the process of intelligent upgrading of traditional industries and strengthens the collaborative innovation of urban agglomerations based on data interconnection platforms^[2]. However, excessive resource concentration has caused a significant siphon effect. Although the digital industry highland with Beijing as the core has generated technological spillovers, it has also exacerbated the imbalance of regional factors, forming a contradictory pattern of “innovation islands” and “industrial faults” coexisting. To this end, the study proposes that the construction of a cross-regional coordination mechanism should consider both the optimization of factor allocation and the removal of institutional barriers, and balance the agglomeration effect and radiation momentum through differentiated policies^[3]. Existing studies have mostly focused on the growth effect of digital economy entities, and have not explored systematic coordination mechanisms enough. This paper innovatively integrates objective empowerment evaluation and coordination degree models, constructs a time-space dual-dimensional analysis framework, and empirically reveals the internal logic of digital technology to solve the “development gradient difference, industrial chain fragmentation, and innovation resource fragmentation”. The research results provide a decision-making basis for optimizing the layout of digital infrastructure and designing a stepped radiation path^[4-9]. It not only improves the theoretical system of regional coordinated development, but also provides an operational practical paradigm for implementing the dual national strategies of “Digital China” and “Beijing-Tianjin-Hebei Coordinated Development”, which has significant practical significance for promoting high-quality regional coordinated development^[10-13].

2 Research Area, Analysis Methods, Data Sources

2.1 Overview of the Research Area

In 2024, Beijing’s GDP will be 4376.07 billion yuan. In 2023, the proportion of the tertiary industry in Beijing will rise to 84.8%, the proportion of the secondary industry will fall to 14.9%, and the proportion of the primary industry will fall slightly to 0.2%. Tianjin’s GDP in 2024 will be 1673.73 billion yuan. In 2013, the proportion of the tertiary industry in Tianjin was 62.7%, the proportion of the secondary industry was 35.7, and the primary industry was 1.6%. Hebei’s GDP in 2024 will be 4394.41 billion yuan. The proportion of the tertiary industry in Hebei will be 52.4%, the proportion of the secondary industry will be 37.4, and the primary industry will be 10.2%.

2.2 Research Methods

2.2.1 Entropy Method.

The entropy method is an objective weighting method based on information entropy theory. It minimizes the interference of human factors on the allocation of indicator weights through steps such as data standardization, entropy calculation and weight derivation^[12-14]. The specific process includes:

1. Data standardization. Assume that m is the number of cities under the jurisdiction of a province, n is the number of indicators, and x_i represents the i -th indicator. The standardized value of the j -th index of the sample ($i = 1, 2, \dots, m; j = 1, 2, \dots, n$);
2. $\text{MAX } x_{ij}$ and $\text{MIN } x_{ij}$ are the maximum and minimum values of the j th indicator, respectively. In addition, to avoid non-positive values, the standardized data is shifted by 0.0001. Positive indicators: $X_{ij} = \frac{x_{ij} - \text{min}x_{ij}}{\text{max}x_{ij} - \text{min}x_{ij}}$; Negative indicators: $X_{ij} = \frac{\text{max}x_{ij} - x_{ij}}{\text{max}x_{ij} - \text{min}x_{ij}}$, i -th sample of the j -th index: $p_{ij} = \frac{x_{ij}}{\sum_{i=1}^m x_{ij}}$
3. Calculate the index value of the i -th sample of the j -th index : $p_{ij} = \frac{x_{ij}}{\sum_{i=1}^m x_{ij}}$
4. Calculate the entropy value of the j -th indicator: $w_j = \frac{g_j}{\sum_{j=1}^n g_j}$
5. Calculate the coefficient of variation of the j -th indicator: $g_j = 1 - e_j$
6. Calculate the comprehensive score of each city: $s_{ij} = \sum_{j=1}^n w_j \times p_{ij}$

2.2.2 Coupling Coordination Analysis Model.

Coupling refers to the phenomenon that two or more systems are integrated and linked through some internal mechanism. Coordination refers to the transmission and conversion of matter, information and energy between two subsystems [15-16]. This study uses the coupling coordination model to measure the digital life and economic structure of the Beijing-Tianjin-Hebei region and the coupling coordination relationship between the two, effectively judging the coordination of the economic structure and digital life coupling process of Chengdu and Chongqing in different years, so as to analyze the coordinated path and development model of the urban digital economy in the Beijing-Tianjin-Hebei region. The calculation formula is:

$$G = \left[\frac{C_1 \times C_2}{(C_1 + C_2/2)^2} \right]^{1/2}$$

$$D = \sqrt{G \times T}, T = \alpha C_1 + \beta C_2$$

Among them, $\alpha + \beta = 1$; G represents the coupling degree of the two systems, T is the comprehensive evaluation index; C_1 and C_2 are the comprehensive index values of the economic structure and digital life system, respectively, and α and β are the weights of the two systems; D represents the coupling coordination degree, and its value range is $[0, 1]$. The larger the value, the better the coordination between the systems. This paper tests the coordinated development of economic structure and digital life, so the two systems are equally important, so $\alpha = \beta = 1/2$. Drawing on existing research [17], the coupling coordination degree is divided into 10 levels, Coordination level 1 is Extremely disordered, Coordination level 2 is Serious disorder, and Coordination level 10 is High-quality coordination.

2.3 Data Sources

The original data of this article mainly come from the statistical yearbooks and annual statistical bulletins of Beijing, Hebei Province and Tianjin Province, and the data from 2019 to 2023 are selected in the time range [18-21].

3 Data Analysis

3.1 Construction of Indicator System

The evaluation index system of this study is constructed based on the standards of scientificity, relevance and operability. The indicators are shown in Table 1.

Table 1. Evaluation system of digital life and development potential of economic structure in Beijing-Tianjin-Hebei region

Subsystem	First level indicator	Secondary indicators	Positive/ Negative Indica- tor	unit
Economic Structure	Economic scale growth	GDP growth rate X1	just	(%)
		GDP X2	just	(100 million yuan)
	Quality of economic development	GDP per capita X 3	just	(Yuan)
		Proportion of tertiary industry X4	just	(%)
	Total local fiscal revenue	Total local fiscal revenue X5	just	(10,000 yuan)
	Market demand	Total retail sales of consumer goods X6	just	(100 million yuan)
	Fixed asset investment	Fixed asset investment growth rate X7	just	(%)
	Consumption	Urban residents' consumption expenditure X8	just	(Yuan)
		Per capita disposable income of urban residents X9	just	(Yuan)
Ratio of urban consumption expenditure to total income X10		just	(%)	
Digital Life	Income and distribution	Average wage of employees in non-private enterprises (urban) X11	just	(Yuan)
Public service support		Number of health institutions X12	just	(individual)
Develop- ment po- tential	Proportion of urban population	Proportion of urban population X13	just	(%)

The evaluation system of economic structure, digital life and development potential in the Beijing-Tianjin-Hebei region consists of an economic structure subsystem and a digital life subsystem, with a total of 9 first-level indicators selected. Among them, 5 first-level indicators of the economic structure subsystem, 3 first-level indicators of

digital life, and 1 first-level indicator of development potential were selected. A total of 13 second -level indicators were selected, and all of them were positive indicators.

3.2 Comprehensive Evaluation

According to the urban digital economy rating index system constructed in Table 2, the entropy method is used to analyze the weights of each first-level and second-level index. The weight value of the evaluation index represents the importance level of the index to the overall evaluation system. The results show that the first-level index weights of Beijing City are income and distribution (0.2393), economic development quality (0.1665), economic scale and growth(0.1643), and fixed asset investment (0.1066); the first -level index weights of Tianjin City are income and distribution (0.2393), economic development quality(0.1762), economic scale and growth(0.1652), and urban population ratio (0.0862); the first - level index weights of Hebei Province are income and distribution (0.2412), economic scale growth(0.1717), economic development quality(0.1642), and local fiscal revenue (0.0831). Overall, the six first-level indicators of income and distribution, economic development quality, economic scale and growth, fixed asset investment, urban population proportion and local fiscal revenue are more important for the evaluation of the economic digital life and development potential of the Beijing-Tianjin-Hebei region. from Figure 1, the overall comprehensive score of the digital economy development level of the Beijing - Tianjin-Hebei region from 2019 to 2023 showed a significant downward trend, indicating that the digital economy development level and capacity of the Beijing-Tianjin-Hebei region have declined in the five years from 2019 to 2023. The comprehensive score of the digital economy development level of Beijing has dropped from 0.3102 in 2019 to 0.0434 in 2023, a decrease of 0.2668; the comprehensive score of the digital economy development level of Tianjin has dropped from 0.218837 in 2019 to 0.143262 in 2023, a decrease of 0.075574; the comprehensive score of the digital economy development level of Hebei Province has dropped from 0.292702 in 2019 to 0.033902 in 2023, a decrease of 0.258799.

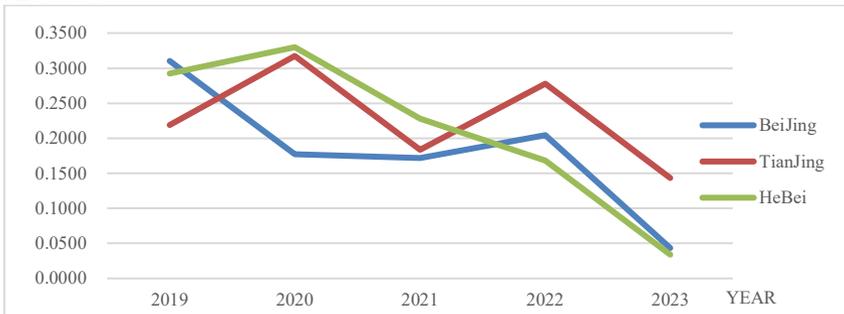


Fig. 1. Trend of comprehensive scores of digital economy development levels in various cities from 2019 to 2023

The reason is that the Beijing Municipal Government issued the Beijing New Industry Prohibition and Restriction Catalogue (2018 Edition) in September 2018, which

“required that the construction and expansion of Internet data services be prohibited at the city level [22-26].

For data centers in information processing and storage support services, the construction and expansion of data centers are completely prohibited in the central urban area. “As the core area of computing power demand in the country, Beijing’s policies have led to limited incremental supply of local data centers. Second, the “Beijing New Industry Prohibition and Restriction Catalogue”, revised in 2018, expanded the scope of relocation of manufacturing and wholesale markets. This series of policies resulted in only 12% of Beijing’s relocated enterprises settling in Hebei from 2019 to 2022, and 78% flowing to the Yangtze River Delta and Pearl River Delta. The 2019 “Action Plan for Comprehensive Control of Air Pollution in the Beijing-Tianjin-Hebei Region and Surrounding Areas in Autumn and Winter” requires “eliminating 20 million tons of coking capacity and promoting ultra-low emission transformation of steel enterprises.” “As a result, the profits of industrial enterprises above designated size in Hebei Province fell by 18.7% year-on-year in 2019, among which the manufacturing investment in cities such as Shijiazhuang and Xingtai fell by 25%. In 2019, the Hebei Provincial Government planned to reduce steel production capacity by 14 million tons, coal by 10 million tons, and coke by 3 million tons, and required the withdrawal of all steel production capacity in Zhangjiakou and Langfang. Although the de-capacity policy has optimized environmental quality, the corresponding economic guarantee policy has not been established, causing Hebei to fall into a vicious cycle of “environmental protection first- economic recession-people’s livelihood damage”. In 2019, Beijing-Tianjin-Hebei continued the “four restrictions” policy (purchase restrictions, loan restrictions, price restrictions, and sales restrictions) to strictly control speculative demand. In addition, the “Beijing-Tianjin-Hebei Manufacturing Digital Transformation Action Plan (2023-2025)” policy, the “Beijing-Tianjin-Hebei Coordinated Development Plan for the 14th Five-Year Plan Period” (2021), the “Beijing-Tianjin-Hebei Hydrogen Energy Industry Coordinated Development Demonstration Group Implementation Plan” (2023), the “Beijing-Tianjin-Hebei Energy Coordinated Development Action Plan (2021-2025)”, and the “Beijing-Tianjin-Hebei National Technology Innovation Center Construction Plan” (2021) and other plans, showing that the Beijing-Tianjin-Hebei region has begun to transform to high-quality development in sectors such as energy, ecological protection and green development, industrial upgrading, and innovative industries, and is committed to restoring the ecology, upgrading industries, developing innovation-driven and technological collaboration, optimizing the regional industrial layout, and building a “pioneer zone for Chinese-style modernization construction.”

Specifically, from 2019 to 2023, the development level of the digital economy in Beijing-Tianjin-Hebei has shown an unstable or even slowly declining trend. However, it can be seen that the economy in 2022 has a sign of rebounding, but this is only a rebound after the weakness during the epidemic and the impact of policies; in addition, Beijing’s permanent population has experienced negative growth for six consecutive years, and Hebei’s population has continued to decline sharply from 2021 to 2023. Therefore, it has also had a negative impact on the development trend of the digital economy in the entire Beijing-Tianjin-Hebei region. The Beijing economy accounts for a large proportion of the Beijing-Tianjin-Hebei economic belt (such as 41.79% in

2021), and the overall coordinated development of Beijing-Tianjin- Hebei has also been impacted. In addition, the trend of the digital economy comprehensive score in the Beijing-Tianjin-Hebei region from 2019 to 2023 is exactly the same, which proves the internal coordination of the Beijing-Tianjin-Hebei region as a digital economy development economic circle from the side. However, in terms of economy, Hebei is still in a transition period. The continuous de-capacity and structural adjustment of the traditional steel industry in Hebei will cause a certain recession in the short term that will damage the development of the economy.

3.3 Coupling Analysis

The coupling coordination degree and corresponding coupling coordination degree of each subsystem of the urban digital economy in Beijing, Tianjin and Hebei Province from 2019 to 2023 are calculated as shown in Table 2.

Table 2. Coupling coordination degree D value of Beijing, Tianjin and Hebei Province from 2019 to 2023 Coupling coordination calculation results

Year	Coupling degree C value	Coupling coordination D value	Coordination level	Coupling coordination degree
2019	0.989	0.520	6	Barely coordinated
2020	0.963	0.514	6	Barely coordinated
2021	0.993	0.439	5	On the verge of disorder
2022	0.979	0.461	5	On the verge of disorder
2023	0.809	0.244	3	Moderate Disorder

Combined with Table 2, it can be seen the period of 2019-2023, the changes in the coupling coordination degree of the three subsystems of the digital economy in the Beijing-Tianjin-Hebei region basically showed a downward trend, gradually transitioning from barely coordinated to moderately uncoordinated, the coordination level dropped from 6 to 3, and the coupling coordination value dropped from 0.520 in 2019 to 0.244 in 2023, indicating that the coupling coordination degree in the Beijing-Tianjin-Hebei region has declined. Although there was a brief rebound in 2022, the reason should be that the rebound brought about by the policy adjustment under the epidemic increased from 0.439 in 2021 to 0.461 in 2022, but the increase was small, and the downward trend failed to change. It dropped to 0.244 in 2023.

4 Findings and Discussion

In summary, according to the comprehensive evaluation results of the Beijing-Tianjin-Hebei region, Beijing's digital economy comprehensive score is higher than that of the other two cities, which means that the digital economy development of Beijing, Tianjin and Hebei is not as good as that of Beijing; the results of the coupling and coordination analysis show that the average coupling and coordination degree of the Beijing-Tianjin-

Hebei region from 2019 to 2023 has generally declined. Through the coupling and coordination analysis, it can be seen that the internal connection of the digital economy subsystem in the Beijing-Tianjin-Hebei region is getting weaker and weaker, and there is a problem of insufficient coordinated development. This shows that the development of the digital economy in the Beijing-Tianjin-Hebei region has not fully played the leading role of Beijing, and the digital economy of Beijing-Tianjin-Hebei has failed to support each other. At this stage, we should focus on removing obstacles to coordinated development, creating a good industrial division of labor chain, and improving the digital governance system. Based on the numerical values of relevant digital economy development indicators of Beijing, Tianjin and Hebei from 2019 to 2023, and based on the synergistic purpose of urban digital economy development, an “entropy weight-coupling coordination model” was constructed. The entropy method and coupling coordination algorithm were used to quantitatively obtain the comprehensive scores and coupling coordination degrees of digital economy development in Beijing, Tianjin and Hebei, and it was found that Beijing’s comprehensive score and coupling coordination degree were higher than those of Tianjin and Hebei. Statistics show that the coordinated development capacity of the digital economy in the Beijing-Tianjin-Hebei region has been decreasing year by year from 2019 to 2023.

5 Conclusion

Combined with the findings and conclusions of this paper, the following suggestions are put forward: (1) The government should improve coordination policies, establish a regional policy coordination mechanism, and reduce policy conflicts; establish a sound interest distribution mechanism to avoid excessively uneven distribution of talents and enterprises, so that the coordinated development level of digital economy in various cities in the Beijing-Tianjin-Hebei region is higher. It can learn from the Guangdong-Hong Kong-Macao “Digital Bay Area” to promote data transactions and eliminate policy conflicts. (2) Deepen the coordination of the industrial chain and accelerate digital transformation. The Beijing-Tianjin-Hebei region should give full play to its own advantages. Beijing should focus on core technology research, Tianjin should focus on strengthening manufacturing digitalization, and Hebei should focus on the downstream links of digital industrialization. The three provinces and cities should reasonably position their respective divisions of labor; at the same time, Beijing-Tianjin-Hebei can follow the experience of Chengdu-Chongqing’s “regional-industry-enterprise” digital transformation promotion center development, increase policy support for the digital transformation of small and medium-sized private enterprises, provide appropriate subsidies for enterprise development costs, and provide free small and medium-sized open platforms. (3) Strengthen infrastructure construction, promote coordinated development of infrastructure, strengthen the construction of digital infrastructure in Hebei, and improve dynamic adjustment mechanisms. (4) Establish a risk control system and implement hierarchical protection. Government departments will conduct stress tests on the risk resistance of key industrial supply chains, establish a data protection system of “two-site backup + local processing”, carry out cross-border data flow pilots in Xiongan

New Area, and implement risk management and control with “business data as the center” at the enterprise level, including hierarchical protection, multi-layer connection, and dynamic authorization. A cross-regional digital collaboration platform should be formed before 2028, so that resources can be shared, factors can be circulated, and risks can be controlled, the efficiency of regional digital collaboration can be increased by more than 30%, the number of major risk events can be reduced by more than 50%, and a situation in which development and security promote each other should be formed.

Due to the limited data obtained, this paper only investigates the development level of digital economy in Beijing-Tianjin-Hebei region ^[24]. In addition, due to the situation that data statistics were not updated and data was difficult to obtain when collecting data, some indicators could only be abandoned when establishing the index system, and only the main indicators that affect the entire evaluation index system were selected. Beijing-Tianjin-Hebei must accurately position itself and plan a new path for digital development. Break the barriers as soon as possible, activate existing resources, optimize resource allocation, and strengthen synergy and linkage; jointly write a new chapter of high-quality development. It is also necessary to further strengthen the construction of regional cooperation mechanisms, strengthen inter-regional policy integration and factor circulation, accelerate the interconnection and integration of information infrastructure, and continuously enhance the basic conditions for coordinated development. In terms of industrial layout, we must build on our respective advantages, form a differentiated development pattern, promote the reasonable distribution of innovative resources, and promote complementary advantages and benign interaction; on the basis of coordinating development and security, we must improve the institutional system of coordinated governance, improve the connection of rules, the integration of standards and safety prevention and control, build a solid bottom-line thinking, and promote Beijing-Tianjin-Hebei to form a higher level of coordinated development in multiple ways, forming a powerful driving force for cultivating new momentum and stimulating new vitality, contributing to the construction of a new development pattern, and creating a model area for coordinated development in the Beijing-Tianjin-Hebei region.

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