

# A Study on Digital Economic Development Levels Based on the Topsis Comprehensive Evaluation Method: A Case Study of the North China Region

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**Abstract.** In the global process of digital transformation, the development of the digital economy is an essential pathway to drive industrial upgrading and enhance comprehensive competitiveness. This study focuses on the North China region, first constructing an evaluation model for the level of digital economic development, which includes 21 indicators across three tiers. Subsequently, the Analytic Hierarchy Process (AHP) is employed to assign weights to the evaluation indicators of digital economic development. Following this, the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) comprehensive evaluation method is utilized to measure and comparatively analyze the digital economic development scores of provinces and municipalities within the North China region. Finally, linear regression analysis, based on data from 2013 to 2023, is used to forecast the digital economic development status of the North China region from 2024 to 2034. The study concludes that Hebei Province and Beijing consistently rank in the top two positions, while the Inner Mongolia Autonomous Region and Tianjin currently occupy the bottom two positions. However, Tianjin is projected to improve and surpass the Inner Mongolia Autonomous Region, securing the fourth position in the future, indicating a favorable development trend. The study ultimately proposes that the North China region should deepen industrial upgrading and strengthen infrastructure, contributing to the discourse on digital economic development.

**Keywords:** Digital Economy; AHP; TOPSIS Comprehensive Evaluation Method; Linear Regression; North China Region.

## 1. Introduction

In recent years, with the continuous innovation and breakthroughs in 5G and artificial intelligence technologies in China, the industrial structure of the digital economy has been increasingly perfected, and total factor productivity has been steadily enhanced, signifying that China's digital economy has entered a new phase of rapid growth. At the G20 Summit in 2022, President Xi Jinping emphasized the need to "jointly create an open, inclusive, fair, just, and non-discriminatory environment for the development of the digital economy, and to advance international cooperation in the digital industrialization and industrial digitalization to unleash the potential of the digital economy in driving global growth."<sup>[1]</sup> By 2023, the scale of China's digital economy had reached 53.9 trillion yuan, with a year-on-year increase of 3.7 trillion yuan.<sup>[2]</sup> The digital economy accounted for 42.8% of GDP, and its contribution to GDP growth had reached 66.45%.<sup>[3]</sup> Along with the vigorous development of China's digital economy, the North China region has emerged as a significant force in driving the country's digital economic progress. The North China region connects the Northeast, Northwest, and Central Plains, with the Beijing-Tianjin-Hebei city cluster serving as a vital economic growth pole, exhibiting an economic trend of radiating and driving the surrounding areas with Beijing as the core. In 2023, Beijing's digital economy added value reached 1876.67 billion yuan, with a year-on-year growth of 8.5%, making it the city with the strongest digital economy competitiveness in China overall.<sup>[4]</sup> In addition, surrounding cities such as Tianjin and Hebei have also continuously strengthened the construction of digital economy infrastructure to promote digital economic development. However, during the development of the digital economy, the North China region still faces issues such as regional development imbalance, insufficient capacity for scientific and

technological innovation, and difficulties in digital transformation of traditional industries. Therefore, it is particularly important to explore the digital economic development of the North China region.

Based on this, this paper first constructs primary, secondary, and tertiary indicators of factors influencing the digital economy. Subsequently, the AHP is employed to assign weights to these indicators. Finally, the Topsis comprehensive evaluation method is utilized to compare the digital economic development scores of the North China region at the provincial and municipal levels. The key factors affecting digital economic development are ultimately identified to provide policy recommendations for the government.

## 2. Literature Review

### 2.1. Research on Factors Influencing the Digital Economy

Asif Raihan<sup>[5]</sup> investigated the relationship between the digital economy and sustainability, revealing that while the digital economy presents numerous opportunities for sustainability, it also faces challenges such as increased electronic waste, the digital divide, and intensified monopolies. He proposed solutions to these challenges to advance sustainability through the digital economy. Chihiro Watanabe, Kashif Naveed, and Yuji Tou<sup>[6]</sup> examined solutions to the limitations of gross domestic product (GDP) statistics in measuring digital economic development by analyzing the co-evolution of people's preferences shifting from economic functionality to hyper-functionality, advancements in information and communication technology (ICT), and paradigm shifts. Their study provided new insights into measuring the digital economy, emphasizing its impact on productivity and statistical methodologies. Aina B. Otarbayeva, Akimzhan A. Arupov, and Madina M. Abaidullayeva<sup>[7]</sup> employed scientific methods such as analysis, abstraction, forecasting, and deduction, using Kazakhstan and the European Union as examples, to highlight the influence of inter-country interactions, macroeconomic conditions, and political stability on the digital economy. Ellen A. Abanga and Stephen Dotse<sup>[8]</sup> utilized comparative literature review methods to analyze the impact of artificial intelligence on the digital economy in South Asia, Southeast Asia, and Africa. Their findings indicated that South Asia and Southeast Asia have made significant progress in adopting artificial intelligence, while Africa faces challenges such as inadequate infrastructure. However, both regions hold potential for leveraging artificial intelligence to promote inclusive digital economic growth and transformation.

Ding Rui, Fu Jun, and Zhu Yuqi<sup>[9]</sup> employed exploratory spatiotemporal data analysis and geographic detectors to examine the spatiotemporal characteristics of digital economy resilience in 279 Chinese cities from 2011 to 2021. Their results demonstrated that factors such as telecommunications revenue and the number of mobile phone users play important roles in digital economy resilience. Xu Zhenjian, Lv Lachang, and Xin Xiaohua<sup>[10]</sup> used a comprehensive evaluation index system and spatial statistical analysis models to identify significant regional disparities in China's digital economic development, with eastern coastal cities and provincial capitals leading the way. They also found that ICT industry agglomeration and government support have significant positive impacts. Lv Yanqin and Fan Tianzheng<sup>[11]</sup> applied entropy weight methods and the Dagum Gini coefficient to determine that the level of tertiary industry development, marketization, and economic level are decisive factors in digital economic development. Zhong Yexi and Mao Weisheng<sup>[12]</sup> utilized spatial econometric models and mathematical statistical analysis to explore the spatial pattern of digital economy levels in the Yangtze River Economic Belt. They discovered that information technology level, urban hierarchy, and industrial structure have significant impacts on digital economic development, while economic level, population size, and human capital have relatively smaller effects. Based on these findings, they proposed recommendations for policy formulation, enhanced cooperation, and innovation in digital economy models.

## 2.2. Research on the Development Trends of the Digital Economy

Teoh and Mahmood<sup>[13]</sup> highlighted that the significance of digital elements has surged in the era of digital transformation, with national economic development increasingly reliant on the digital realm. They emphasized that the National Cybersecurity Strategy (NCSS) is a crucial element in safeguarding and realizing the digital economy. Khamraeva S. N., Mafe Carla Ruiz, and Silvia Sanz Bias<sup>[14]</sup> explored the characteristics and trends of digital economic development in Uzbekistan, both domestically and internationally. They noted that the digitalization of economic processes has become a pervasive trend, encompassing information and communication networks as well as all economic activities. Additionally, the study underscored the necessity of active government participation in promoting and supporting promising digital innovations across various economic sectors. O. V. Pavelko, O. O. Doroshenko, and Z. V. Los<sup>[15]</sup> selected the Global Connectivity Index and employed relevant regression analysis for mathematical modeling. Their research examined Ukraine's position in the global sustainable development trends from the perspective of the digital economy, highlighting the role of digital transformation in achieving sustainable development goals and providing a novel perspective for studying digital economic development trends. Vladimir Bilozubenko, Olha Yatchuk, and Elżbieta Wolanin<sup>[16]</sup> utilized cluster analysis to compare the parameters of digital economic development among European Union countries. They depicted the landscape of digital economic development in the EU and assessed the digital divide, providing a theoretical basis for decision-making aimed at bridging this gap.

Ding Congming, Chen Zhiyuan, and Li Yangyang<sup>[17]</sup> employed paired samples of prefecture-level cities to empirically examine the impact of the digital economy on balanced economic development between the northern and southern regions. They found that balanced development of the digital economy can help narrow the economic divide between the two regions and proposed accelerating the economic growth of the northern region and reducing the digital divide to promote coordinated development between the north and south. Du Xuefeng<sup>[18]</sup> conducted an international comparison of global digital economic development. He noted that although China's digital economy has entered a new phase of deep integration with the real economy, it still faces challenges such as weak foundational innovation capabilities, low levels of industrial digitalization, and weak digital economy governance. He suggested strengthening core technology innovation, building digital platforms, and accelerating the empowerment of digital technology across all industries. Wang Lian, Zhou Zhihao, and Zhang Weixing<sup>[19]</sup> explored the impact of the digital economy on the new development pattern. They pointed out that the digital economy has to some extent exacerbated the differences in the level of development of the new pattern among regions and proposed suggestions such as improving the efficiency of resource allocation and developing digital economy strategies tailored to local conditions. Liu Haoyan<sup>[20]</sup>, from an international comparative perspective, highlighted that China's digital economy has demonstrated a unique development path and model. He emphasized the need for China to delve deeply into technological innovation and other fields and to gain a profound understanding of the Chinese path to digital economic development, thereby propelling China's digital economy to a higher level.

## 2.3. Review and Commentary on the Literature

In summary, foreign scholars have primarily focused on the relationships between the digital economy and other entities, as well as the development status in different countries, while simultaneously emphasizing the impact of inter-country interactions and government participation on the digital economy. In contrast, Chinese scholars have paid more attention to the spatiotemporal characteristics, regional disparities, and influencing factors of China's digital economy, and have proposed corresponding policy recommendations. However, during the literature review process, it was found that few scholars have conducted comprehensive and systematic evaluations of the regional differences in the digital economy. Moreover, the existing studies often suffer from limited data timeliness and predominantly employ time-series regression methods, making it difficult to measure the degree of digital economic development indices in each region.

Based on these observations, this study first constructs an economic development evaluation model and standardizes the data. Subsequently, the AHP is utilized to assign weights to the indicators of the digital economy. Finally, the Topsis comprehensive evaluation method is applied to conduct an overall assessment of the digital economic development in the North China region at the provincial and municipal levels. This approach aims to identify the key factors influencing the digital economy in the North China region.

### 3. Construction of the Analytic Hierarchy Process

#### 3.1. Preliminary Selection of Indicators and Data Sources

As shown in Table 1, the primary indicator is the level of digital economic development. The secondary indicators consist of four dimensions: digital infrastructure, digital industrialization, industrial digitalization, and digital environment. The tertiary indicators total 15, including the number of mobile phone base stations, the length of optical cable lines, the number of IPv4 addresses, the number of Internet broadband access users, the total volume of telecommunications services, the mobile phone penetration rate, the revenue from information technology services, the revenue from software services, the number of computers per hundred people, the number of websites owned by enterprises, the e-commerce sales of enterprises, the e-commerce procurement of enterprises, the full-time equivalents of R&D personnel, the number of students enrolled in regular colleges and universities, and R&D funding.

**Table 1.** Indicator System for Evaluating the Level of Digital Economic Development

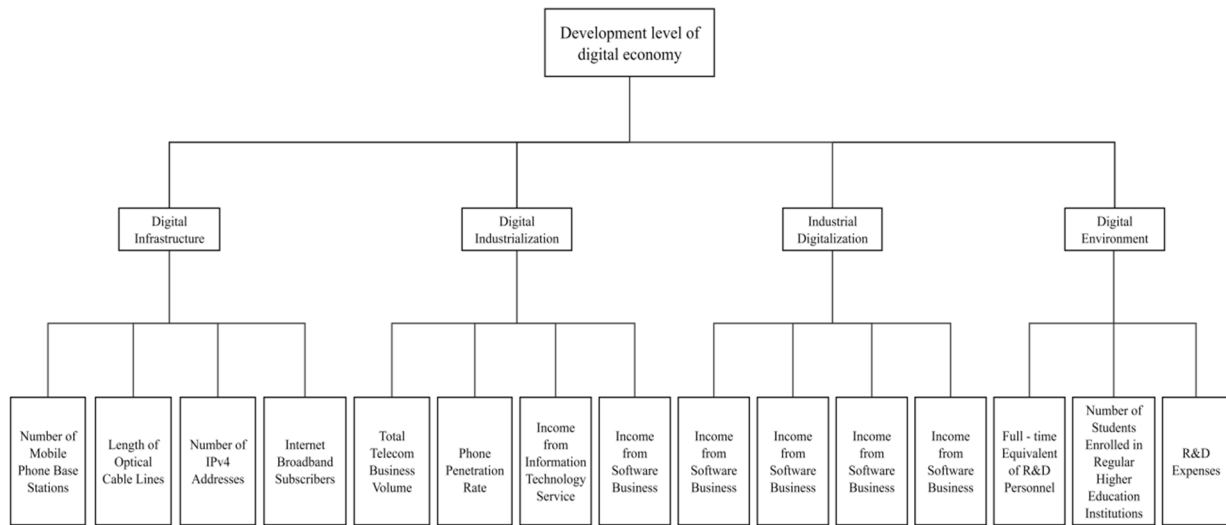
Primary Indicator	Secondary Indicator	Tertiary Indicator
Level of Digital Economic Development	Digital Infrastructure	Number of Mobile Phone Base Stations (in ten thousand units)
		Length of Optical Cable Lines (kilometers)
		Number of IPv4 Addresses (in ten thousand units)
		Number of Internet Broadband Access Users (in ten thousand households)
	Digital Industrialization	Total Volume of Telecommunications Services (in billion yuan)
		Telephone Penetration Rate (units per hundred people)
		Revenue from Information Technology Services (in billion yuan)
	Industrial Digitalization	Revenue from Software Services (in billion yuan)
		Number of Computers per Hundred People (units)
		Number of Websites Owned by Enterprises (units)
	Digital Environment	E-commerce Sales of Enterprises (in billion yuan)
		E-commerce Procurement Amount of Enterprises (in billion yuan)
		Full-Time Equivalent of R&D Personnel (person-years)
		Number of Students Enrolled in Regular Colleges and Universities (persons)
		R&D Funding (in ten thousand yuan)

The data utilized in this study are sourced from the National Bureau of Statistics of China ([www.stats.gov.cn](http://www.stats.gov.cn)). The dataset comprises panel data, encompassing digital economy-related information from 2013 to 2023.

#### 3.2. Construction of the Analytic Hierarchy Process

##### 3.2.1. Analytic Hierarchy Process Structural Analysis Model

The hierarchical analysis structure model constructed in this study is depicted in Figure 1.



**Figure 1.** Construction of the Analytic Hierarchy Process Structural Analysis Model

### 3.2.2 Construction of the Judgment Matrix

The computational foundation of the AHP is the judgment matrix, the elements of which reflect individuals' perceptions of the relative importance of various factors and directly influence the decision-making outcomes. The elements of the judgment matrix are typically scaled using a 1–9 and their reciprocal values for subsequent operations. In this study, the values of the judgment matrix elements are presented in Table 2.

**Table 2.** Elements of the Judgment Matrix

Scale	Meaning
1	Indicates that the two factors are equally important.
3	Indicates that one factor is slightly more important than the other.
5	Indicates that one factor is distinctly more important than the other.
7	Indicates that one factor is strongly more important than the other.
9	Indicates that one factor is extremely more important than the other.
2, 4, 6, 8	Represents the midpoint between two adjacent judgments.
Reciprocal	If a judgment $B_{ij}$ is made comparing factor $i$ with factor $j$ , then the judgment comparing factor $j$ with factor $i$ is $B_{ji}=1/B_{ij}$

### 3.2.3 Hierarchical Single Sorting and Consistency Check

Hierarchical single sorting refers to the order of importance of each factor in a given layer relative to a particular factor in the layer above. This is represented by the eigenvector of the judgment matrix. For instance, for the judgment matrix  $A$ , the solution vector  $W$  of the eigenproblem  $AW = \lambda_{\max}W$ , after normalization, becomes the sorting weight values of the relative importance of the factors in the same layer with respect to a certain factor in the upper layer. This process is termed hierarchical single sorting.

In hierarchical single sorting, the following formula is employed for calculation and determination of the research results. The random consistency index is presented in Table 3.

Consistency Index (CI):

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (1)$$

$\lambda_{\max}$  represents the maximum eigenvalue of  $A$ .

**Table 3.** Random Consistency Index

Order of the Judgment Matrix n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Consistency Ratio (CR):

$$CR = \frac{CI}{RI} = \frac{\lambda_{\max} - n}{RI \times (n - 1)} \quad (2)$$

During the calculation process, the results of hierarchical single sorting are deemed satisfactory only when the CR is less than 0.1. Otherwise, adjustments to the values of the elements in the judgment matrix are required to ultimately achieve satisfactory results.

### 3.2.4 Hierarchical Total Sorting and Consistency Check

In the hierarchical total sorting, the composite consistency ratio of the p-th layer relative to the first layer is given by the formula:

$$CR^{(p)} = CR^{(p-1)} + \frac{CI^{(p)}}{RI^{(p)}}, p = 3, 4, \dots, s \quad (3)$$

Only when the value of the CR is less than 0.1 is the result of the hierarchical total sorting considered to have satisfactory consistency; otherwise, it is necessary to readjust the values of the elements in the judgment matrix. In this study, the calculated CR value is 0.002959. Therefore, the decision-making outcome is deemed credible, and the construction of the AHP is thus completed.

### 3.3. Table of Indicator Weights

The weights of the tertiary indicators, as derived from the construction of the AHP, are presented in Table 4.

**Table 4.** Indicator Weights Derived from the Analytic Hierarchy Process

Primary Indicator	Secondary Indicator	Tertiary Indicator	Weight of Tertiary Indicator
Level of Digital Economic Development	Digital Infrastructure	Number of Mobile Phone Base Stations	0.1053
		Length of Optical Cable Lines	0.0374
		Number of IPv4 Addresses	0.1053
		Number of Internet Broadband Access Users	0.2967
		Total Volume of Telecommunications Services	0.0806
	Digital Industrialization	Telephone Penetration Rate	0.0161
		Revenue from Information Technology Services	0.0806
		Revenue from Software Services	0.0161
	Industrial Digitalization	Number of Computers per Hundred People	0.0104
		Number of Websites Owned by Enterprises	0.0276
		E-commerce Sales of Enterprises	0.0777
		E-commerce Procurement Amount of Enterprises	0.0777
		Full-Time Equivalent of R&D Personnel	0.0191
	Digital Environment	Number of Students Enrolled in Regular Colleges and Universities	0.0049
		R&D Funding	0.0445

## 4. Construction of the Topsis Comprehensive Evaluation Method

### 4.1. Construction of the Decision Matrix

The decision matrix  $A=(a_{ij})_{m \times n}$  is constructed, where each column represents an evaluation criterion, and each row corresponds to a candidate solution to be evaluated.

### 4.2. Elimination of the Influence of Dimensional Units

To facilitate comparison, the normalization process yields  $B=(b_{ij})_{m \times n}$ , where:  
For attributes of the larger-the-better (benefit) type:

$$x^* = \frac{x - \min}{\max - \min} \quad \text{i.e.} \quad b_{ij} = \frac{a_{ij} - a_j^{\min}}{a_j^{\max} - a_j^{\min}} \quad (4)$$

For attributes of the smaller-the-better (cost) type:

$$x^* = \frac{\max - x}{\max - \min} \quad \text{i.e.} \quad b_{ij} = \frac{a_j^{\max} - a_{ij}}{a_j^{\max} - a_j^{\min}} \quad (5)$$

### 4.3 Assignment of Indicator Weights

Given the varying contributions of each evaluation criterion to the overall assessment outcome, distinct weights are assigned accordingly:  $w=[w_1, \dots, w_n]$ . Multiplying the  $j$ -th column of matrix  $B$  by its corresponding weight  $w_j$  yields the weighted normalized matrix  $C=(c_{ij})_{m \times n}$ .

### 4.4 Determination of the Positive Ideal Solution and the Negative Ideal Solution

Determine the positive ideal solution  $C^+$  and the negative ideal solution  $C^-$ :

$$C^+ = [c_1^+, c_2^+, \dots, c_n^+], C^- = [c_1^-, c_2^-, \dots, c_n^-] \quad (6)$$

Positive ideal solution:

$$c_j^+ = \begin{cases} \max_i c_{ij}, & j \text{ is a maximization attribute,} \\ \min_i c_{ij}, & j \text{ is a minimization attribute,} \end{cases} \quad j = 1, 2, \dots, n \quad (7)$$

Negative ideal solution:

$$c_j^- = \begin{cases} \min_i c_{ij}, & j \text{ is a maximization attribute,} \\ \max_i c_{ij}, & j \text{ is a minimization attribute,} \end{cases} \quad j = 1, 2, \dots, n \quad (8)$$

### 4.5. Calculation of the Distances from the Candidate Solutions to the Positive and Negative Ideal Solutions

The distance from the alternative solution  $a^i$  to the positive ideal solution:

$$d_i^* = \sqrt{\sum_{j=1}^n (c_{ij} - c_j^+)^2}, i = 1, 2, \dots, m \quad (9)$$

The distance from the alternative solution  $a^i$  to the negative ideal solution:

$$d_i^0 = \sqrt{\sum_{j=1}^n (c_{ij} - c_j^-)^2}, i = 1, 2, \dots, m \quad (10)$$

#### 4.6. Calculation of the Relative Closeness of the Candidate Solutions

Calculate the relative closeness (evaluation reference value) of the candidate solutions:

$$f_i = \frac{d_i^0}{d_i^0 + d_i^*}, i = 1, \dots, m \quad (11)$$

Subsequently, the alternatives are ranked in descending order based on  $f_i$ , thereby establishing the priority sequence of the candidate solutions.

#### 4.7. Empirical Analysis Results of the Topsis Comprehensive Evaluation Method

By employing the aforementioned procedures and utilizing Python 3.11 software for computation, the overall scores for the digital economic development levels of provinces and municipalities in the North China region from 2013 to 2023 were obtained, as presented in Table 5.

**Table 5.** Overall Scores of Digital Economic Development

Year Province	Beijing	Tianjin	Hebei	Shanxi	Inner Mongolia
2013	0.4139 (2)	0.0574 (5)	0.6637 (1)	0.3128 (3)	0.1253 (4)
2014	0.4109 (2)	0.0599 (5)	0.6646 (1)	0.3061 (3)	0.1206 (4)
2015	0.4060 (2)	0.0580 (5)	0.6667 (1)	0.3029 (3)	0.1170 (4)
2016	0.4018 (2)	0.0639 (5)	0.6696 (1)	0.3086 (3)	0.1238 (4)
2017	0.3991 (2)	0.0661 (5)	0.6677 (1)	0.2901 (3)	0.1229 (4)
2018	0.4108 (2)	0.0852 (5)	0.6712 (1)	0.2913 (3)	0.1377 (4)
2019	0.4233 (2)	0.0855 (5)	0.6784 (1)	0.3061 (3)	0.1301 (4)
2020	0.4364 (2)	0.1295 (4)	0.6733 (1)	0.3108 (3)	0.1252 (5)
2021	0.4740 (2)	0.1364 (4)	0.6680 (1)	0.3718 (3)	0.1339 (5)
2022	0.5115 (2)	0.1313 (5)	0.6749 (1)	0.3655 (3)	0.1390 (4)
2023	0.4968 (2)	0.1311 (5)	0.7322 (1)	0.3807 (3)	0.1436 (4)

## 5. Linear Regression

### 5.1. Construction of the Regression Model

In the regression model, the year is designated as the independent variable  $x$ , and the overall index of digital economic development levels for each province, obtained through the Topsis comprehensive evaluation method, is designated as the dependent variable  $y$ . The relationship between future years and the overall scores of digital economic development for each province and municipality can be represented using a simple linear regression model as follows:

$$y = a + bx + e \quad (12)$$

where  $a$  is the constant of the regression model,  $b$  is the coefficient of the regression model, and  $e$  is the residual term.

The years from 2013 to 2023 and the overall scores of digital economic development for each province satisfy the following linear relationship:

$$y_i = a + bx_i + e_i \quad (13)$$

Specifically, for Beijing, the future year is denoted as the independent variable  $x_b$ , and the overall score of digital economic development is denoted as the dependent variable  $y_b$ ; for Tianjin, the future year is  $x_t$  and the overall score is  $y_t$ ; for Hebei, the future year is  $x_h$  and the overall score is  $y_h$ ; for Shanxi, the future year is  $x_s$  and the overall score is  $y_s$ ; and for Inner Mongolia, the future year is  $x_n$  and the overall score is  $y_n$ . Separate linear regression models are constructed for each region as follows:

$$\begin{aligned} y_b &= a_b + b_b x_b \\ y_t &= a_t + b_t x_t \\ y_h &= a_h + b_h x_h \\ y_s &= a_s + b_s x_s \\ y_n &= a_n + b_n x_n \end{aligned} \quad (14)$$

The computational results are presented in Table 6.

**Table 6.** Computed Model Parameters

parameter	Beijing	Tianjin	Hebei	Shanxi	Inner Mongolia
a	0.3742	0.0346	0.6534	0.2786	0.1167
b	0.0101	0.0095	0.0037	0.0073	0.0021

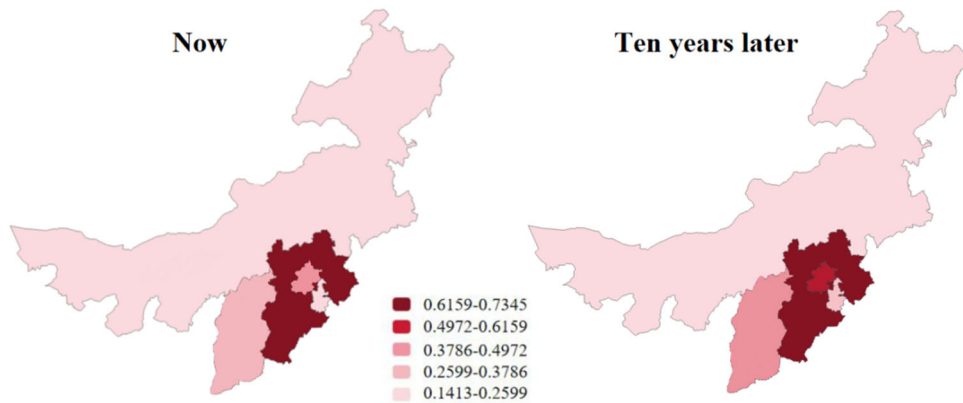
## 5.2. Analysis of the Prediction Results

Based on the regression model, the comprehensive evaluation scores and ranking results for the digital economy in the North China region from 2024 to 2034 are predicted and presented in Table 7.

**Table 7.** Predicted Overall Scores and Rankings of Digital Economic Development

Year Province	Beijing	Tianjin	Hebei	Shanxi	Inner Mongolia
2024	0.4957 (2)	0.1480 (4)	0.6976 (1)	0.3663 (3)	0.1413 (5)
2025	0.5059 (2)	0.1575 (4)	0.7013 (1)	0.3736 (3)	0.1434 (5)
2026	0.5160 (2)	0.1669 (4)	0.7050 (1)	0.3809 (3)	0.1454 (5)
2027	0.5261 (2)	0.1764 (4)	0.7087 (1)	0.3882 (3)	0.1475 (5)
2028	0.5363 (2)	0.1858 (4)	0.7124 (1)	0.3955 (3)	0.1495 (5)
2029	0.5464 (2)	0.1953 (4)	0.7160 (1)	0.4028 (3)	0.1516 (5)
2030	0.5565 (2)	0.2048 (4)	0.7197 (1)	0.4102 (3)	0.1536 (5)
2031	0.5666 (2)	0.2142 (4)	0.7234 (1)	0.4175 (3)	0.1557 (5)
2032	0.5768 (2)	0.2237 (4)	0.7271 (1)	0.4248 (3)	0.1578 (5)
2033	0.5869 (2)	0.2331 (4)	0.7308 (1)	0.4321 (3)	0.1598 (5)
2034	0.5970 (2)	0.2426 (4)	0.7345 (1)	0.4394 (3)	0.1619 (5)

By visualizing the current and projected digital economic development in the North China region over the next decade based on the predicted results, a heatmap as shown in Figure 2 can be generated.



**Figure 2.** Heatmap of Digital Economic Development Levels in the North China Region in 2024 and 2034

## 6. Conclusions

(1) First, Hebei Province has the highest level of digital economic development in the North China region, with a score of 0.7322. Over the next decade, its development is projected to steadily improve, with a predicted value of 0.7345 in 2034, maintaining its position as the top-ranked province in the region. Hebei Province has significant advantages in indicators such as the full-time equivalents of R&D personnel and the number of students enrolled in regular colleges and universities, indicating a strong performance in education. Additionally, the province's optical cable line length consistently surpasses that of other provinces and municipalities across all years, reflecting substantial investment in the physical infrastructure of communication networks.

(2) Second and third are Beijing and Shanxi Province, with scores of 0.4968 and 0.3807, respectively. Their predicted values for 2034 are 0.5970 and 0.4394, respectively, both showing improvement while maintaining their relative rankings. Beijing has demonstrated significant progress and excels in multiple key areas of the digital economy. It leads other provinces and municipalities in the number of IPv4 addresses, revenue from information technology services, software business income, and e-commerce sales and procurement by enterprises, highlighting its strong digital industrialization capabilities. Moreover, Beijing has seen a substantial increase in R&D funding from 2013 to 2023, with significant human and financial resource investments driving continuous innovation and the emergence of new technologies and business models in the digital economy.

Shanxi Province has shown steady improvement in its digital economy-related indicators and is on a positive trajectory. However, its growth rate is relatively lower than that of Beijing. Over the past decade, Shanxi has continuously advanced in digital infrastructure construction, expanding its network coverage. Nevertheless, its digital industrialization lags behind, with significant gaps in information technology service revenue and software business income compared to Beijing and Tianjin. The province faces challenges in attracting high-end talent and high-quality enterprises in the digital economy sector and needs to further enhance its capacity for scientific and technological innovation.

(3) Finally, the Inner Mongolia Autonomous Region and Tianjin Municipality rank fourth and fifth, with scores of 0.1436 and 0.1311, respectively. Their predicted values for 2034 are 0.1619 and 0.2426, respectively. The digital economic development level of the Inner Mongolia Autonomous Region is relatively low in the North China region, with slow overall improvement. In terms of digital industrialization, the region has a smaller scale of information technology service revenue and software business income, indicating a weaker industrial base. Inner Mongolia needs to leverage its resource advantages to explore a digital economic development model suitable for the local context, increase investment in the digital economy, and enhance its overall development level.

Tianjin Municipality has a relatively optimistic future development trend and is projected to surpass Inner Mongolia to become the fourth-ranked region between 2024 and 2034. Compared to Beijing and Hebei, Tianjin still has gaps in digital economic development, with a need to accelerate the digital transformation of enterprises and deepen and expand the application of digital technologies in traditional industries. However, Tianjin has shown steady growth in information technology service revenue and software business income and has increased investment in industrial digitalization, allowing it to overtake Inner Mongolia. Tianjin should contribute to building a collaborative innovation community in the Beijing-Tianjin-Hebei region and accelerate the development of a digital economy space led by a core and supported by multiple points.

## **7. Suggestions**

### **7.1. Accelerate Innovation-Driven Development to Stimulate Digital Vitality**

The North China region should prioritize the research and development of digital technologies, with the government increasing funding for scientific research and guiding enterprises and social capital to actively participate through policies such as tax incentives and project subsidies. By focusing on core technologies like artificial intelligence, big data, and blockchain, establishing special research funds, and encouraging research institutions and universities to form joint R&D teams, efforts can be concentrated on overcoming technical challenges. This will enhance the core competitiveness of the digital economy and secure an advantageous position in the global digital technology competition.

Talent is the core driving force behind the vigorous development of the digital economy. <sup>[21]</sup> Therefore, the North China region should focus on optimizing the curriculum of digital economy-related majors in universities, increasing the proportion of practical teaching, and co-establishing internship and training bases with enterprises to enhance students' professional skills through practice. This will cultivate professionals who are well-versed in both theory and practice. Additionally, the region can introduce attractive policies, such as housing subsidies and educational benefits for children, to attract high-end digital talent from both domestic and international sources. Establishing a comprehensive talent incentive mechanism to reward individuals who achieve outstanding results in the digital economy will provide ample development opportunities and career advancement channels, fully stimulating the innovative vitality of talent.

### **7.2. Promote Coordinated Development to Narrow Regional Gaps**

The paper reveals significant disparities in digital economic development levels among the provinces and municipalities in the North China region. Therefore, it is necessary to strengthen policy communication and coordination, jointly formulate regional digital economy development plans, unify policy standards, and eliminate barriers to market access and data flow. Implementing a regional digital economy coordination development mechanism <sup>[22]</sup> will address issues encountered during development, promote the free flow of data, technology, and talent within the region, and form a unified, open, and orderly competitive digital economy market, thereby enhancing the overall competitiveness of the North China region.

Furthermore, the development characteristics and advantages of each province and municipality should be clarified to strengthen regional industrial collaboration. <sup>[23]</sup> Beijing can leverage its advantages in digital technology innovation to build technology-sharing platforms and provide technical support and solutions to surrounding areas. Hebei can utilize its manufacturing base to actively undertake digital industry transfers and promote the digital transformation of traditional manufacturing. Tianjin, with its port and financial advantages, can develop industries such as cross-border e-commerce and digital finance. Shanxi Province should tap into its traditional resource advantages, upgrade the coal industry with digital technology, undertake industrial transfers, and promote the integration of the digital economy with traditional manufacturing. The Inner Mongolia Autonomous Region should leverage its own advantages to develop smart agriculture and animal

husbandry, as well as digital platforms for clean energy, undertake related industries, and promote digital cultural tourism. By enhancing industrial collaboration, the North China region can achieve coordinated industrial development and form a complete digital economy industrial chain.

### **7.3. Deepen Industrial Upgrading to Promote Integrated Development**

To accelerate the transformation and upgrading of traditional industries in the North China region, traditional enterprises should be guided to increase their investment in digital transformation, promoting the digitalization of production, management, and marketing processes. Enterprises should be encouraged to introduce digital technologies such as industrial internet and big data analytics to achieve intelligent control of production processes, scientific management decision-making, and diversified expansion of sales channels. Additionally, fostering new digital business models and formats, such as personalized customization, intelligent manufacturing, and online-offline integrated marketing, is crucial for revitalizing traditional industries. Finally, focusing on the frontier fields of the digital industry, efforts should be made to cultivate and expand emerging industries such as cloud computing, the Internet of Things, and digital creativity.

Enhancing the efficiency of enterprise R&D can facilitate digital transformation.<sup>[24]</sup> Therefore, it is important to support digital enterprises in increasing their R&D investment and encourage them to explore multi-field applications of "AI+." The North China region should promote the development of the digital industry towards high-end, intelligent, and green directions, improving the core competitiveness and sustainable development capabilities of the digital industry.

### **7.4. Strengthen Infrastructure to Support Development**

Continuous investment in the construction of digital infrastructure such as 5G networks, fiber-optic broadband, and data centers is fundamental to the digital economic development of the North China region. For areas with lower levels of digital economic development, such as rural and remote regions, diverse approaches such as government subsidies and active participation by enterprises should be used to effectively reduce network construction costs. This will ensure that high-speed and stable network services benefit more areas, helping to bridge the digital divide and laying a solid network foundation for the digital economic development of the North China region.

Additionally, strengthening the research and application of network security technologies and encouraging enterprises and research institutions to develop advanced network security protection technologies will also support the digital economic development of the North China region. Network security plays a crucial role in the current digital economy context.<sup>[25]</sup> The North China region should establish and improve real-time network security monitoring systems to promptly detect and address various network security threats, enhance data security protection, and regulate data collection, storage, and usage processes to ensure the safe and stable operation of the digital economy.

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