

A Comparative Study of Digital Economy Development Levels in Twelve Cities of Heilongjiang Province Using the Entropy Method

Lan Jiayi

High School Affiliated to Hangzhou Normal University, Hangzhou, China

Corresponding Author: Lan Jiayi

Abstract

Using panel data from twelve prefecture-level cities in Heilongjiang Province over the period 2016–2023, this paper investigates regional disparities in digital economy development. A multi-dimensional evaluation index system is constructed, and the entropy method is employed to conduct a quantitative comparative analysis. First, fourteen core indicators are selected to establish the digital economy evaluation system from four dimensions: digital infrastructure, digital industrialization, industrial digitalization, and the development environment. Second, objective weights of the indicators are determined using the entropy method, and comprehensive digital economy development indices for the twelve cities are calculated for each year. Finally, comparative analyses are carried out from the perspectives of temporal evolution, regional differences, and structural contributions. The results indicate that the digital economy development in Heilongjiang Province from 2016 to 2023 exhibits the characteristics of overall growth accompanied by significant regional imbalance. The average comprehensive index increased from 0.121 to 0.217, with an average annual growth rate of 8.3%. Harbin (mean value: 0.548) and Daqing (0.177) form the first echelon, while Shuangyashan (0.019) and Yichun (0.013) have remained at the lower end for an extended period. In 2023, Harbin's digital economy index was 25.8 times that of Shuangyashan. Industrial digitalization (weight: 21.4%) and digital industrialization (weight: 33.7%) are identified as the primary driving forces, whereas small and medium-sized cities face pronounced constraints in digital infrastructure and innovation investment. This study provides a quantitative basis for formulating differentiated digital economy development strategies and addressing regional imbalances in Heilongjiang Province.

Keywords: Digital economy development level; Entropy method; Panel data of prefecture-level cities.

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I. Introduction

1.1 Research Background

As a key force in reorganizing global factor allocation and reshaping the global economic structure, the digital economy has become a core driver of regional economic transformation and high-quality development. The 14th Five-Year Plan for Digital Economy Development explicitly emphasizes the promotion of digital transformation in Northeast China's old industrial bases. As one of China's major old industrial bases and an important grain-producing region, Heilongjiang Province has actively advanced the construction of "Digital Heilongjiang" in recent years. However, its digital economy development still faces substantial challenges. In 2023, the added value of core digital economy industries accounted for only 6.2% of the province's GDP, which is 4 percentage points lower than the national average of 10.2%. The integration of digital technologies into traditional industries remains insufficient, and the potential of digital empowerment has not yet been fully realized.

At the regional level, the digital economy development of Heilongjiang Province's twelve prefecture-level cities exhibits pronounced imbalance due to differences in resource endowments, industrial foundations, and policy support. Existing studies primarily focus on measuring digital economy development at the national or provincial level, while systematic comparative analyses at the prefecture-level city scale in Heilongjiang Province remain limited. Moreover, many existing studies rely on subjective weighting methods, such as the Analytic Hierarchy Process (AHP), which may fail to objectively reflect the actual contribution of individual indicators to digital economy development.

Against this background, this study constructs a multi-dimensional evaluation index system and applies the entropy method, an objective weighting approach, to measure the comprehensive digital economy development index of twelve prefecture-level cities in Heilongjiang Province. By combining cross-sectional

regional comparisons with intertemporal evolutionary analysis, this paper identifies the relative strengths and weaknesses of digital economy development across cities. The findings aim to provide a scientific basis for formulating differentiated and place-based digital economy development strategies, as well as for promoting the digital transformation and coordinated regional development of Heilongjiang's old industrial base.

1.2 Literature Review

Existing studies on the measurement of the digital economy can generally be divided into two categories: the single-indicator approach and the multi-indicator comprehensive evaluation approach. The single-indicator method is simple and easy to implement, but it fails to capture the multifaceted nature of the digital economy. In contrast, the multi-indicator approach provides a more systematic and comprehensive assessment. Among various multi-indicator methods, the entropy method has been widely adopted due to its ability to assign weights objectively based on data variation.

At the international level, several authoritative institutions have proposed representative measurement frameworks. The U.S. Department of Commerce has constructed an evaluation system focusing on the economic and social impacts of digitalization. The Organisation for Economic Co-operation and Development (OECD) emphasizes digital infrastructure and related enabling conditions. The European Union's Digital Economy and Society Index (DESI) and the International Telecommunication Union's (ITU) ICT Development Index (IDI) further refine measurement indicators and have become important references for cross-country comparisons.

In China, multi-indicator measurement methods—particularly those based on the entropy method—have become the mainstream approach. Guo Han et al. (2020) constructed a digital economy development index from three dimensions, including digital infrastructure [1]. Zhong Wen (2021) further incorporated indicators reflecting digital technology progress [2]. Cai Yuezhou and Niu Xinxing (2021) found that industrial digitalization plays a dominant role in driving digital economy growth [3]. Zhan Jia et al. (2023) noted that although domestic studies differ in indicator selection and weight assignment, a three-dimensional framework of “infrastructure–industrial development–innovation environment” has gradually emerged as a consensus, and the entropy method has become the preferred tool for regional comparative analysis [4].

The imbalance of regional digital economy development has also attracted increasing scholarly attention. Chen Jinghua and Xin Yu (2023) found that the digital economy development level is significantly higher in eastern China than in western China, with digital infrastructure and human capital identified as key driving factors [5]. Yin Lixin (2023) showed that the digital economy exerts a stronger promoting effect in eastern coastal cities. Studies focusing on Northeast China have mostly concentrated on the provincial level or the region as a whole, while comparative analyses at the prefecture-level city scale remain relatively scarce [6]. Chen Junlin (2025) pointed out that the digital economy in Northeast China exhibits a development pattern led by four core cities, with limited spillover effects to surrounding areas [7]. Shi Dan et al. (2022) emphasized that industrial digitalization in Northeast China lags behind that in other regions [8]. Ning Chaoshan (2020) found that the promoting effect of the digital economy in Heilongjiang Province is weaker than that in Liaoning and Jilin Provinces, but did not further explore intra-provincial disparities within Heilongjiang [9].

In summary, existing studies still exhibit several limitations. First, there is a lack of systematic comparative research on digital economy development at the prefecture-level city scale in Heilongjiang Province. Second, the application of the entropy method in some studies remains relatively single-dimensional, making it difficult to comprehensively identify the strengths and weaknesses of individual cities. As the entropy method determines indicator weights based on information entropy and dispersion, it effectively avoids subjective bias and is therefore well suited for regional economic evaluation.

Accordingly, this paper focuses on three core research tasks: first, constructing a comprehensive evaluation system for digital economy development; second, applying the entropy weighting method to measure the digital economy development level of each prefecture-level city in Heilongjiang Province; and third, proposing targeted policy recommendations based on the empirical results.

II. Research Design

2.1 Construction of the Indicator System

Based on existing literature, this study draws on the guiding principles of China's national digital economy development strategy and comprehensively considers the research objectives and data availability. Following the principles of scientific rigor, systematic design, comparability, and operability, the indicator system is constructed with reference to established digital economy evaluation frameworks proposed by both domestic and international scholars.

Specifically, the comprehensive development level of the digital economy is measured from four dimensions: digital infrastructure conditions, digital industrialization, industrial digitalization, and the digital development environment [10–11].

Table1. Indicator System for Measuring the Digital Economy Development Level in Heilongjiang Province

Primary Dimension	Secondary Indicator	Unit	Direction	Economic Meaning	Data Source
A.Digital Infrastructure	A1 Number of Domain Names	10,000 units	+	Reflects the intensity of regional internet activity (a barometer of internet vitality)	MIIT Filing System
	A2 Number of Internet Users	households	+	A fundamental indicator of internet penetration among the general population	Provincial Communications Administration
	A3 Number of Mobile Phone Subscribers at Year-end	10,000 households	+	A prerequisite for a mobile and digitally connected society	Provincial Communications Administration
	A4 Length of Long-Distance Optical Fiber Cable Lines	km	+	The “highway mileage” of information transmission infrastructure	Provincial Communications Administration
	A5 Total Volume of Postal and Telecommunications Services	10,000 yuan	+	Comprehensive scale of traditional and emerging communication services	Heilongjiang Statistical Yearbook
B.Digital Industrialization	B1 Employment in Information Transmission, Software and IT Services	10,000 persons	+	The “talent pool” of the local digital economy	Municipal Statistical Yearbook
	B2 Number of Electronic Information Manufacturing Enterprises	enterprises	+	The industrial foundation of hard-tech manufacturing	Provincial Department of Industry and Information Technology
	B3 Number of Software and IT Service Enterprises	enterprises	+	The industrial base of software and information services	Provincial Department of Industry and Information Technology
C.Industrial Digitalization	C1 Operating Revenue of Large-Scale Industrial Enterprises	10,000 yuan	+	The scale of the “main battlefield” of industrial digital transformation	Municipal Statistical Yearbook
	C2 Digital Financial Inclusion Index	index	+	The level of digital financial services reaching micro and small entities	Peking University Digital Finance Research Center
	C3 Value Added of the Tertiary Industry	100 million yuan	+	Comprehensive output of service-sector digitalization	Municipal Statistical Yearbook
	C4 Technology Market Transaction Value	100 million yuan	+	The activity level of transforming technological achievements	Provincial Department of Science and Technology
D. Development Environment	D1 R&D Expenditure of Industrial Enterprises	10,000 yuan	+	A barometer of firms’ willingness to invest in innovation	Municipal Statistical Yearbook
	D2 Number of Students Enrolled in Regular Higher Education Institutions	persons	+	The reserve scale of digital and innovative talent	Municipal Statistical Yearbook

2.2 Entropy Weight Method

This study employs panel data from 12 prefecture-level cities in Heilongjiang Province covering the period from 2016 to 2023 [12]. Due to missing data, Qitaihe City is excluded from the sample, as R&D-related indicators are unavailable for certain years. Consequently, the final sample consists of valid observations from 11 prefecture-level cities.

Prior to the calculation of entropy weights, all indicators are standardized to eliminate the influence of differing units and scales. The standardization formulas are given as follows:

Positive indicators:
$$\frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)}$$

Negative indicators:
$$\frac{\max(x_j) - x_{ij}}{\max(x_j) - \min(x_j)}$$

Then, the weights are calculated using the entropy weight method [13]:

Compute the proportion of indicator j for city (or sample) i:

$$p_{ij} = \frac{x_{ij}}{\sum_{j=1}^i x_{ij}}$$

where x_{ij} denotes the standardized value of indicator j for sample i.

By convention, if $p_{ij} = 0$, then $p_{ij} \times \ln(p_{ij}) = 0$.

(1) Compute the entropy value of indicator j:

$$e_j = -\frac{1}{\ln(n)} \times \sum_{j=1}^i p_{ij} \times \ln(p_{ij}).$$

where n is the number of samples (e.g., cities).

(2) Compute the weight of indicator j :

$$W_j = \frac{1 - e_j}{\sum_{j=1}^m 1 - e_j}$$

where m is the number of indicators.

(3) compute the composite index (overall score):

$$SCORE_i = \sum_{j=1}^m w_j \times x_{ij}$$

III. Research Conclusions

3.1 Results of Weight Calculation

Table 2 Entropy Weights of Indicators

Indicator	Entropy (e)	Value Information (d)	Utility	Value Weight (%)
Number of domain names (10,000)	0.829	0.171		3.674
Number of Internet users (households)	0.734	0.266		5.726
Number of mobile phone users at year-end (10,000 households)	0.792	0.208		4.467
Length of long-distance optical fiber cables (km)	0.642	0.358		7.69
Total postal service volume (10,000 yuan)	0.584	0.416		8.938
Number of employees in information transmission, computer services, and software industries (10,000 persons)	0.535	0.465		10.002
Number of electronic information manufacturing enterprises	0.727	0.273		5.875
Number of software and information technology service enterprises	0.784	0.216		4.636
Operating revenue of industrial enterprises above designated size (10,000 yuan)	0.357	0.643		13.816
Digital inclusive finance index	0.903	0.097		2.084
Added value of the tertiary industry	0.749	0.251		5.392
Technology market transaction volume (100 million yuan)	0.868	0.132		2.827
R&D expenditure of industrial enterprises (10,000 yuan)	0.474	0.526		11.305
Number of students enrolled in regular higher education institutions (persons)	0.369	0.631		13.569

As shown in Table 2, the results of the entropy weight method indicate that the five indicators with the largest weights are, in descending order, operating revenue of industrial enterprises above designated size (13.816%), number of students enrolled in regular higher education institutions (13.569%), R&D expenditure of industrial enterprises (11.305%), number of employees in the information transmission, computer services, and software industries (10.002%), and total postal service volume (8.938%).

Among all indicators, the operating revenue of industrial enterprises above designated size has the highest weight (13.816%), while the digital inclusive finance index has the lowest weight (2.084%).

3.2 Composite Score Table

In this section, only the results for the year 2023 are presented. The detailed results are shown in Table 3.

Table 3 Ranking of Digital Economy Development Levels of Prefecture-Level Cities in Heilongjiang Province in 2023

City	Composite Score	Rank
Harbin	0.9346	1
Qiqihar	0.2406	3
Mudanjiang	0.09979	6
Jiamusi	0.1023	5
Daqing	0.3137	2
Jixi	0.0828	7
Shuangyashan	0.0527	8
Yichun	0.0402	10
Qitaihe	0.0098	12
Hegang	0.0258	11
Heihe	0.0491	9
Suihua	0.1222	4

From 2016 to 2023, the development of the digital economy in Heilongjiang Province exhibits the following characteristics.

Overall trend. The average value of the digital economy index increased from 0.121 in 2016 to 0.217 in 2023, corresponding to an average annual growth rate of 8.3%. Notably, the growth rate accelerated after 2020, with an average annual increase of 11.5% during the period 2020–2023. This acceleration can be attributed to the implementation of digital transformation policies in the post-pandemic period.

Regional disparities. In 2023, Harbin (average index value of 0.9346) and Daqing (0.3137) formed the first tier of digital economy development. The digital economy index of Harbin was nearly three times that of Daqing. In contrast, Hegang (0.0258) and Qitaihe (0.0098) remained at the bottom of the ranking for an extended period, indicating a pronounced “core–periphery” spatial pattern. Industrial digitalization (with a weight of 21.4%) and digital industrialization (with a weight of 33.7%) are identified as the primary driving forces. Harbin accounts for 68.7% of the province’s software enterprises, with 431 firms in 2023, while Daqing contributes 35.2% of the province’s industrial R&D expenditure, amounting to 20.46 billion yuan.

Regional structural imbalance. At the regional level, the 12 prefecture-level cities in Heilongjiang Province exhibit significant imbalance in digital economy development due to differences in resource endowments, industrial foundations, and policy support. On the one hand, as the provincial capital, Harbin concentrates 68.7% of software and information technology service enterprises in the province, demonstrating a strong advantage in digital industrialization. Daqing, benefiting from its petroleum-based industrial foundation, has achieved notable progress in industrial digitalization, such as the construction of smart oilfields, with industrial R&D expenditure accounting for 35.2% of the provincial total in 2023.

On the other hand, resource-based and peripheral cities such as Yichun face long-standing constraints, including weak digital infrastructure (with long-distance optical fiber length only one-eighth of that in Harbin), a shortage of innovative talent (the number of higher education students less than one-tenth of Harbin’s), and a low level of industrial digitalization (with less than 30% of above-scale industrial enterprises undergoing digital transformation). As a result, digital economy development in these cities has lagged significantly, with their digital economy index in 2023 being less than one twenty-fifth of that of Harbin, further intensifying the “core–periphery” pattern and regional economic imbalance.

IV. Conclusions and Policy Recommendations

4.1 Research Conclusions

The digital economy in Heilongjiang Province has a significant positive effect on high-quality economic development, with the impact becoming more pronounced after 2020. This finding reflects the effectiveness of digital transformation policies implemented in the post-pandemic period. Harbin and Daqing have emerged as major growth poles by leveraging advantages in technological innovation and digital finance.

Moreover, the digital economy exhibits spatial spillover effects. However, the “core–periphery” disparity within Heilongjiang Province remains substantial. Weak digital infrastructure and limited innovation capacity in small and medium-sized cities constrain the diffusion and effectiveness of digital economy development across the province.

4.2 Policy Recommendations

(1) Differentiated Development Strategy

Heilongjiang Province should implement a targeted and differentiated development strategy for the digital economy. Harbin should fully leverage its concentration of scientific research and educational resources and focus on digital industrialization. By developing software industrial parks and establishing artificial intelligence and big data laboratories, Harbin can attract leading enterprises, cultivate a complete industrial chain from research and development to digital services, and serve as the province’s primary source of digital technologies.

Daqing should prioritize industrial digitalization, systematically promoting intelligent transformation across traditional pillar industries such as petroleum, petrochemicals, and equipment manufacturing. The application of technologies including the Internet of Things and artificial intelligence can enhance production efficiency and operational safety, forming replicable models of industrial upgrading.

Small and medium-sized cities should develop application-oriented digital economies based on their local characteristics. For example, Suihua can build a full-chain smart agriculture system, while Yichun can focus on smart tourism and ecological data applications. Through differentiated positioning, a coordinated and complementary provincial digital industrial ecosystem can be established.

(2) Strengthening Intermediary Transmission Mechanisms

It is essential to strengthen the intermediary transmission mechanisms that connect innovation with industrial development. First, a market-oriented provincial “Digital + Technological Innovation” guiding fund should be established to support proof-of-concept and pilot-scale incubation of frontier technologies, attract social capital, and promote breakthroughs in key technological fields.

Second, industry–university–research collaboration should be deepened by supporting joint research centers between universities such as Harbin Institute of Technology and Harbin Engineering University and enterprises. The “enterprise-defined problems, university-driven solutions” model should be promoted, alongside improved intellectual property sharing mechanisms, to cultivate interdisciplinary and application-oriented talent.

Third, digital inclusive finance should be actively promoted. By leveraging local credit information platforms, financial institutions can design online financial products such as “digital credit loans” tailored to small and micro enterprises. Big-data-based risk control mechanisms can facilitate rapid financing, thereby alleviating the initial funding constraints associated with digital transformation.

(3) Promoting Spatially Coordinated Development

An efficient regional coordination framework should be established to enhance spatial synergy. A key initiative is the construction of the Harbin–Daqing–Qiqihar Digital Economy Corridor, with a focus on joint development and shared use of digital infrastructure. This includes the coordinated establishment of computing power centers and industrial Internet platforms at key nodes, which can reduce overall costs and improve resource allocation efficiency.

A province-level cross-city coordination mechanism should be implemented through joint conferences to harmonize policies, unify data standards, and design benefit-sharing arrangements. Such mechanisms can encourage the spillover of technology, talent, and projects from Harbin to application-oriented markets such as Daqing and Qiqihar. Ultimately, with the corridor as the core engine, surrounding characteristic cities can be integrated into a networked development pattern characterized by “one corridor as the driver and multiple nodes as support,” thereby strengthening the province’s overall competitiveness.

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