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Research on coupling coordination measurement and driving factors of digital new productivity and high-quality development of logistics industry in Beijing-Tianjin-Hebei region

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Abstract. In the context of the digital economy, digital new-quality productivity is reshaping the high-quality development of the logistics industry, while logistics provides key application scenarios and endogenous momentum for its cultivation. This study explores the coupling coordination mechanism and evolutionary characteristics between the two systems in the Beijing–Tianjin–Hebei region. Using regional data from 2016 to 2023, a comprehensive evaluation system is constructed, and a coupling coordination model combined with grey relational analysis is applied to examine inter-system relationships and driving factors. The results show that both digital new-quality productivity and logistics quality exhibit steady upward trends. The coupling coordination degree evolves from a fluctuating adjustment stage to recovery and then toward stable optimization, with clear regional heterogeneity. Technological innovation and infrastructure development are identified as core drivers, while urbanization, openness, and government support play important supporting roles. This study not only empirically clarifies the synergistic evolution mechanism between digital new-quality productivity and high-quality logistics development, but also provides references for optimizing regional collaborative paths and formulating differentiated policies.

Keywords: Beijing-Tianjin-Hebei region, digital new productive forces, logistics industry, coupling coordination, driving factors

1. Introduction

All images in the main text must ensure sufficient clarity to clearly display the content within the images. All formulas, tables, and program codes in the article must be in an editable format and should not be presented as photos or screenshots. All references must be cited in the main text. President Xi Jinping emphasized that "developing new productive forces is an inherent requirement and key focus for advancing high-quality development", directly linking these forces with quality-driven progress. The digital new productive forces, characterized by digital technologies as their core and data elements as critical resources, have emerged as the driving force propelling the national economy and modern industrial systems toward higher-quality development. As a foundational service sector supporting economic circulation, the logistics industry's high-quality growth equally relies on the widespread adoption of digital technologies like 5G, IoT, and big data. Meanwhile, through diverse application scenarios and intelligent demands, the logistics sector actively fuels continuous innovation in digital new productive forces. Therefore, studying the synergistic relationship between digital new productive forces and logistics industry development holds significant theoretical and practical value for revealing industrial collaboration mechanisms in the digital economy era, optimizing regional resource allocation, and promoting high-quality regional economic integration.

Current research on digital new-quality productivity and high-quality development in the logistics industry has become an increasingly prominent field. Jiying Wu & Wenli Zhan [1] propose that new-quality productivity demonstrates advanced productivity characteristics of high efficiency, quality, green intelligence, and smart features through mechanisms such as technological innovation, talent aggregation, and industrial structure upgrading, playing a core driving role in promoting high-quality industrial transformation. Zhou Wen and Ling Yun [2] argue that new-quality productivity not only represents a leap in productivity forms but also serves as a key driver for high-quality economic development. This transition not only reshapes productivity structures but also injects critical momentum into high-quality economic growth. Xiaogang Zhu et al. [3] point out that the digital economy significantly impacts the high-quality development of the logistics industry through technological empowerment, factor reorganization, and industrial structure optimization. When digitalization surpasses a critical threshold, it effectively enhances the logistics industry's efficiency, innovation capabilities, and green development levels. Xiaohong Ren et al. [4] find that policies significantly boost entrepreneurial vitality in the logistics sector by promoting digital infrastructure construction, stimulating digital innovation vitality, and attracting talent aggregation, thereby accelerating the industry's transition to high-quality development. This effect is particularly evident in advanced cities and e-commerce demonstration cities. Song Dan and Xu Zheng [5] propose that new-quality productivity and digital logistics are data-driven. The former promotes industrial upgrading through cost reduction, efficiency improvement, incremental expansion, and green transformation, while the latter achieves systemic optimization through organizational reform, talent cultivation, and data element flow. Fan Luhui [6] noted that data-driven approaches and technological innovations have enhanced the resilience and stability of the logistics industry chain through digital new-quality productivity. Mehmood et al. [7] argued that this productivity model, characterized by digital technology integration, significantly improves green operational performance and regional resource integration efficiency by strengthening cross-regional information connectivity and collaborative resource allocation mechanisms. Wang Cuimin [8] observed that while regional logistics sectors have established policy coordination and institutional linkage foundations in the digital economy context, challenges such as small enterprise scale, superficial technology adoption, inadequate e-commerce integration, and talent mismatch continue to hinder deep integration of digital elements with logistics systems. Xinyuan Zhang et al. [9] emphasized that in the Beijing-Tianjin-Hebei metropolitan area, new-quality productivity drives circular economy development through resource efficiency improvements, industrial structure optimization, and technological innovation, achieving coordinated progress in carbon reduction, pollution control, green expansion, and economic growth. Liang Kai [10] further highlighted a regional disparity in digital industry and logistics development, with Beijing and Tianjin leading while Hebei lags behind, revealing significant gaps in integration levels and ineffective collaborative clustering effects. Overall, while most literature addresses high-quality development of digital new-quality productivity and logistics, existing studies predominantly focus on isolated systems rather than exploring their systemic interactions and coordinated mechanisms.

The Beijing-Tianjin-Hebei region, China's first national strategic coordinated development zone, has positioned logistics as the "backbone" of the real economy. This sector plays a pioneering role in relieving Beijing's non-capital functions and supporting the "dual circulation" economic model. In 2023, the region's logistics industry generated 564.35 billion yuan in added value, with annual freight volumes surpassing 3.4 billion tons (The data is sourced from China Industrial Economic Information Network https://www.cinic.org.cn/xy/gdcj/1554594.html). The area boasts abundant scientific innovation resources, while Beijing's International Science and Technology Innovation Center demonstrates significant spillover effects. Cutting-edge digital technologies—including big data, IoT, AI, and blockchain—have created ideal conditions for logistics upgrading. Using the Beijing-Tianjin-Hebei region as a case study, this paper examines the coupling mechanisms and driving forces between digital productivity and high-quality logistics development. Through constructing an evaluation index system and analytical models, it clarifies their interaction pathways, coordination levels, and influencing factors, providing actionable insights for regional logistics digital transformation and collaborative development strategies.

2. Analysis of the theoretical mechanism of coupling coordination

Digital new-quality productivity represents the concrete manifestation of productivity in the digital era. With digital technology as its core driving force and data elements as key inputs, it integrates next-generation information technologies (AI, big data, cloud computing, blockchain) with traditional production factors to establish a productivity system fundamentally composed of digital labor force, digital labor objects, and digital production means [6]. The high-quality development of the logistics industry, under the digital economy framework, is supported by infrastructure, transportation networks, information platforms, and financial-policy systems. Through optimized resource allocation and operational methods, it forms a modern logistics development system characterized by innovation, coordination, green development, openness, and sharing [11, 12]. This framework comprehensively evaluates the logistics sector's progress in technological advancement, regional collaboration, low-carbon transition, international connectivity, and public services. These two systems define the basic components of digital new-quality productivity and logistics industry development at two levels—the production factor system and industrial operation system—respectively, providing theoretical foundations for subsequent coupling analysis in indicator selection and model construction.Example of the operating mechanism (see Figure 1).

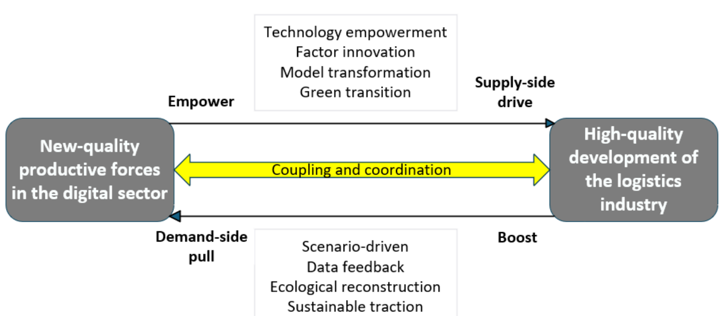

Figure 1. Coupling coordination mechanism between digital new quality productivity and high-quality development of logistics industry

2.1. Digital new productivity empowers high-quality development of logistics industry

The new digital productivity, driven by the integrated synergy of digital workers, digital work objects, and digital production resources, injects sustained momentum into the high-quality development of the logistics industry. Firstly, digital workers optimize warehousing, transportation, and distribution processes through digital skills and innovation capabilities, enhancing the industry's innovation and coordination. Secondly, digital work objects center on data and information to achieve visualized and intelligent supply chain management, improving resource allocation efficiency and supporting coordinated and green development. Finally, digital production resources—including smart terminals, cloud platforms, and IoT infrastructure—provide technical support for logistics operations, expand cross-border logistics and smart supply chains, and promote open development. Meanwhile, the construction of digital infrastructure and sharing platforms facilitates balanced flow of logistics resources, enabling shared development. Overall, the new digital productivity drives comprehensive advancement in the logistics industry across five dimensions—innovation, coordination, green development, openness, and sharing—through the synergy of talent, data, and technology.

2.2. High-quality development of logistics industry boosts growth of digital new productivity

The high-quality development of the logistics industry drives the formation and enhancement of new digital productivity through five key dimensions: innovation, coordination, green practices, openness, and sharing. In the innovation dimension, increased R&D investment and practical scenarios in frontline production provide digital workers with opportunities for skill refinement and knowledge accumulation, facilitating technology implementation and iterative optimization. Regarding coordination, integrated supply chains, expanded logistics networks, and data circulation enable more efficient information processing and resource allocation for digital labor objects. In terms of green and open practices, energy-saving measures, international logistics expansion, and cross-border trade create application scenarios for digital production materials that emphasize energy efficiency and cross-regional collaboration. Through the sharing dimension, the coverage expansion of logistics infrastructure and service networks enhances digital technology accessibility, allowing three types of digital elements to be efficiently applied across broader spatial dimensions. Overall, the high-quality development of the logistics industry drives continuous iteration and evolution of new digital productivity across three dimensions—skills, data, and technology—through demand-driven mechanisms, scenario feedback, and resource restructuring.

In summary, digital new-quality productivity and the high-quality development of the logistics industry exhibit a bidirectional interactive and co-evolutionary relationship. The former provides technological, data, and talent support for the logistics industry in five dimensions—innovation, coordination, green development, openness, and sharing—through digital laborers, digital labor objects, and digital production resources. Conversely, the latter drives the iterative upgrading of digital new-quality productivity through demand traction, scenario feedback, and resource optimization. Under a dynamic feedback mechanism, these two systems mutually reinforce each other, jointly supporting the digital transformation and high-quality development of regional economies.

3. Data and model method

The preceding analysis has theoretically elucidated the interactive mechanisms between the digital new-quality productivity system and the high-quality evolution of the logistics industry, demonstrating their bidirectional coupling of elements and functions. To examine this mechanism's regional manifestations, this study establishes a scientific indicator framework: First, a coupling coordination model is employed to measure the integrated development and mutual synergy between these two systems in the Beijing-Tianjin-Hebei region. Subsequently, a grey relational analysis model is applied to identify key factors influencing the evolution of coordination levels.

3.1. Indicator system construction and data sources

Digital new-quality productivity, a novel form of productivity driven by digital technology, fundamentally reshapes production methods and factor structures through digital element reorganization and technological innovation. This approach achieves synergistic improvements in efficiency, innovation, and structural optimization, characterized by intelligence, integration, and innovation orientation. Building on Fan Luhui et al.'s methodology [6], this study overcomes the limitations of traditional indicator systems in reflecting digital features. It establishes a comprehensive evaluation system aligned with the digital economy's characteristics, selecting eight indicators from three dimensions—digital laborers, digital labor objects, and digital production means—to measure the level of digital new-quality productivity in the Beijing-Tianjin-Hebei region (see Table 1).

Table 1. Evaluation index system of digital new quality productivity

System metrics	primary indicator	secondary indicator	unit	attribute	weight
Figure new quality productive forces	figure labourer	Number of employees in information transmission, software and information technology services/total number of employees	%	+	0.278
		number of students in higher education per 100,000 population	human being	+	0.097
	figure subject of labour	The proportion of value from core industries in the digital economy to GDP	%	+	0.138
		Telecom business volume/Region GDP	%	+	0.177
		Postal service volume/Region GDP	%	+	0.077
	figure means of production	Number of broadband internet users per 100 people	household per 100 people	+	0.049
		Mobile phone users per 100 population	household per 100 people	+	0.126
		Digital Inclusive Finance		+	0.057

Note: 1.The weights are calculated using the entropy weight method. 2."core industries in the digital economy" Primarily encompassing the manufacturing of computers, communications, and other electronic equipment, as well as information transmission, software, and information technology services--National Bureau of Statistics, "*Statistical Classification of the Digital Economy and Its Core Industries (2021)*". 3."Digital Inclusive Finance" is sourced from the Digital Finance Research Center of Peking University (http://idf.pku.edu.cn).

The key to achieving high-quality development in the logistics industry lies in enhancing efficiency and optimizing structure, thereby enabling the logistics system to play a greater role in supporting industrial upgrading, reducing social operational costs, and strengthening economic resilience. This aligns with the overarching requirements of high-quality economic development, emphasizing innovation-driven growth, green and low-carbon practices, efficient collaboration, and open sharing. Based on this, this paper references the research by Xue Yang et al. [12] and integrates the new development philosophy to select ten specific indicators across five dimensions—innovation, coordination, green development, openness, and environmental sustainability—to construct an evaluation system for high-quality logistics industry development (see Table 2).

Table 2. Evaluation index system for high-quality development of logistics industry

System metrics	primary indicator	secondary indicator	unit	attribute	weight
Logistics industry High-quality development	Bring forth new ideas	Full-time equivalent of R&D personnel per 10,000 population	per capita	+	0.146
		R&D expenditure/Regional GDP	%	+	0.145
	Coordinate	gross retail sales per capita	ten thousand yuan per person	+	0.160
		Logistics industry production value/Regional GDP	%	+	0.109
	Green	energy consumption per unit GDP	10,000 tons of standard coal per 100 million yuan	-	0.054
		carbon emission intensity	tons per 10,000 yuan	-	0.058
	Come into bloom	Total value of goods import and export / GDP of the region	%	+	0.096
		Foreign direct investment / regional GDP	%	+	0.108
	Enjoy together	per capita express delivery volume	Items/person	+	0.072
		per capita ownership of trucks	vehicle/person	+	0.051

Note: The weights are calculated using the entropy weight method.

This study focuses on the Beijing-Tianjin-Hebei region, covering the period from 2016 to 2023. Data sources include the *Statistical Yearbooks of Beijing, Tianjin, and Hebei*, the *China Internet Network Information Center (CNNIC) Annual Report*, Wind Database, the State Post Bureau, as well as annual statistical bulletins on national economic and social development and government work reports from various regions. Missing data for certain years were supplemented using linear interpolation.

3.2. Research methods and model selection

3.2.1. Entropy weight method

The entropy weight method is based on the information entropy theory. It measures the information entropy of each index to set the weight, thus avoiding the deviation caused by subjective weighting. This method can objectively reflect the relative contribution of each index in the comprehensive evaluation, combining the advantages of simple calculation and wide applicability. The specific steps are as follows [equations (1)-(6)]:

3.2.1.1 Dimensionless Index

Positive indicator: $$y_{ij} = \frac{x_{ij} - min_i x_{ij}}{max_i x_{ij} - min_i x_{ij}} \quad (1)$$

Negative indicator: $$y_{ij} = \frac{max_i x_{ij} - x_{ij}}{max_i x_{ij} - min_i x_{ij}} \quad (2)$$

Where: $xijyijminixijmaxixij$ represents the j-th indicator data in the i-th year, the unranked quantized data, the minimum value among all indicators, and the maximum value among all indicators. For positive indicators, the higher the value, the better; for negative indicators, the lower the value, the better.

3.2.1.2 Indicator normalization

$$p_{ij} = \frac{y_{ij}}{\sum_{i=1}^{m} y_{ij}}, j = 1, \ldots, n. \quad (3)$$

Where: $y_{ij} p_{ij} \sum_{i=1}^{m} y_{ij}$ represents the standardized indicator value, the weight of the i-th object under the j -th indicator, and the sum of all data for the j-th indicator.

3.2.1.3 Calculation of Information Entropy

$$k = \frac{1}{lnm}, e_j = -k \sum_{i=1}^{m} p_{ij} ln p_{ij}, \quad j = 1, \ldots, n. \quad (4)$$

Where: The entropy $e_j e_j \in$ values of each indicator are m[0,1], where m represents the indices from 2015 to 2023, with a total of 27 indices.

3.2.1.4 Calculate the coefficient of variation for each indicator

$$d_j = 1 - e_j, \quad j = 1, \ldots, n. \quad (5)$$

Where: d_j is the coefficient of variation.

3.2.1.5 Calculate the indicator weights

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j}, \sum_{j=1}^{n} w_j = 1. \quad (6)$$

Where: $w_j \sum_{j=1}^{n} d_j$ represents the weight of each indicator, and is the sum of the difference coefficients of each indicator.

3.2.2. Comprehensive development level evaluation model

After establishing the indicator system and assigning weights through the entropy weight method, this study employs a linear weighted average to derive the subsystem's composite score, quantitatively measuring the overall development level of digital new-quality productivity and the high-quality growth of the logistics industry. The model, based on multi-dimensional indicators, reveals the internal coordination and development quality of the system. It not only overcomes the limitations of single-indicator evaluation but also provides a continuous and comparable benchmark for subsequent coupling coordination models and grey relational analysis, enhancing the systematicness and scientific rigor of the research conclusions. The calculation formula is as equation (7):

$$U_i = \sum_{j=1}^{n} w_j \cdot x_{ij} i = 1, \ldots, m. U_i x_{ij} w_j \quad (7)$$

Where: represents the system's comprehensive development index in year i, the standardized value of the i-th object on the j-th indicator, and the weight of the j-th indicator calculated by the entropy weight method.

3.2.3. Coupling coordination degree model

The coupling coordination degree model, derived from classical physics' coupling concept, is commonly used to analyze the interactive coordination level among multiple systems. In the study of digital new-quality productivity and high-quality development of the logistics industry in Beijing-Tianjin-Hebei region, this model can accurately reveal the interaction intensity between the two and their co-evolutionary trends.

3.2.3.1 Calculate the coupling degree C-equation (8)

$$C = \frac{2\cdot\sqrt{U_1\cdot U_2}}{U_1+U_2} \tag{8}$$

Where: U_1 and U_2 respectively represent the comprehensive level indices of the digital new quality productivity and the high-quality development of the logistics industry subsystems. C denotes the coupling degree between the two systems, with a value range of (0,1). A higher value indicates stronger inter-system interaction.

3.2.3.2 Calculate the Comprehensive Coordination Index T-equation (9)

$$T = \alpha U_1 + \beta U_2 \tag{9}$$

Where: T is the coupling coordination coefficient, and $\alpha = \beta = 1/2$, which indicates that digital new quality productivity and high-quality development of logistics industry are two equally important systems.

3.2.3.3 Calculation of coupling coordination degree-equation (10)

$$D = \sqrt{C \times T} \tag{10}$$

Where: D denotes the coupling coordination degree. A higher value indicates better coupling coordination between systems and a higher coordination level. Based on existing research and the findings of this study, the coupling coordination degree is categorized into 10 levels, as detailed in Table 3.

Table 3. Classification of coupling coordination degree

	interval of coupling coordination degree D	coordination level	coupling coordination degree
	[0.0~0.1)	1	Severe imbalance
	[0.1~0.2)	2	major maladjustment
disregulation	[0.2~0.3)	3	Moderate dysregulation
	[0.3~0.4)	4	Mild dysregulation
	[0.4~0.5)	5	approaching to depletion
	[0.5~0.6)	6	barely coordinated
transitional harmony	[0.6~0.7)	7	primary coordination
	[0.7~0.8)	8	intermediate coordination
harmonious development	[0.8~0.9)	9	Good coordination
	[0.9~1.0]	10	high quality coordination

Note: The classification of coupling coordination degree levels is referenced from the study by Zhang Qin and Pan Chunhua [13].

3.2.4. Grey correlation degree model

The grey relational model stands as a cornerstone of grey system theory, capable of reliably quantifying the relative strength of correlations between factors and system development levels even in scenarios with scarce samples or incomplete/inaccurate data. Unlike traditional methods that focus on numerical values, this approach emphasizes the synchronization of sequential trends. Building upon the measurement of coupling coordination degree, this study employs grey relational analysis to identify key drivers that significantly enhance the coupling coordination between digital new-quality productivity and the high-quality development of the logistics industry.

3.2.4.1 Calculation of Grey Correlation Coefficient-equation (11)

$$\xi_i(k) = \frac{|x_0(k)-x_i(k)|+\rho|x_0(k)-x_i(k)|}{|x_0(k)-x_i(k)|+\rho|x_0(k)-x_i(k)|} \tag{11}$$

Where: is $|x_0(k) - x_i(k)|\rho$ the absolute difference between the standardized reference sequence and the comparison sequence at year k ; is the resolution coefficient, with a value range of (0,1), typically set to 0.5.

3.2.4.2 Calculation of Grey Correlation Degree-equation (12)

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n}\xi_i(k) \tag{12}$$

Where: n is the number of feature sequences.

4. Empirical results analysis

4.1. Comprehensive development level evaluation of two systems in Beijing-Tianjin-Hebei region

4.1.1. Overall evaluation of comprehensive development level

As shown in Figure 2, the integrated development levels of the digital new-quality productivity and high-quality logistics systems in the Beijing-Tianjin-Hebei region exhibited a sustained upward trend from 2016 to 2023, with periodic fluctuations. The digital new-quality productivity (U1) surged from 0.059 in 2016 to 0.569 in 2020, marking a 9.6-fold increase. Although it briefly dipped to 0.393 in 2021 due to external shocks, it rebounded in subsequent years and reached 0.564 by 2023, demonstrating resilience and sustained momentum in digital economy development. The high-quality logistics development (U2) also showed rapid growth, rising from 0.288 in 2016 to 0.766 in 2023. After a brief stagnation and decline in 2017, it gradually recovered, forming a U-shaped curve of "initial decline followed by recovery". Since 2021, U2's growth rate has significantly accelerated, outpacing the digital new-quality productivity system. Overall, the Beijing-Tianjin-Hebei region has achieved upward development in both digital new-quality productivity and logistics industries, reflecting how earlier policy and technological investments laid the foundation for subsequent industrial upgrades, driving both systems toward higher development levels.

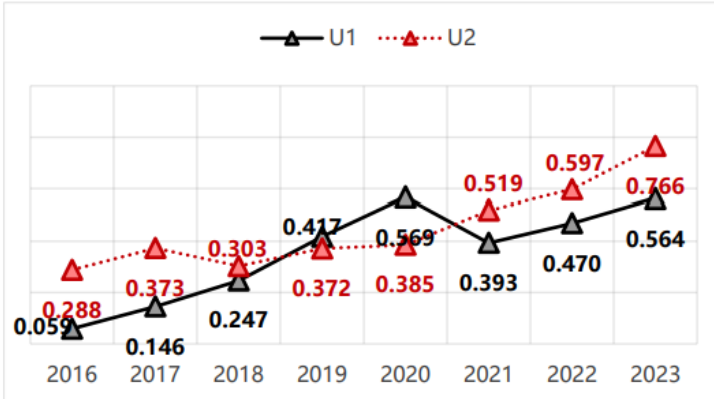

Figure 2. Integrated development level of the Beijing-Tianjin-Hebei region

4.1.2. Regional evaluation of comprehensive development level

By region, the digital new quality productivity (U1) and high-quality development of the logistics industry (U2) in Beijing-Tianjin-Hebei region showed steady growth from 2016 to 2023, but with significant regional disparities and distinct structural characteristics (see Figures 3 and 4). Beijing's U1 rose from 0.470 to 0.653, while U2 increased from 0.549 to 0.680, maintaining its leading position. Tianjin's U1 climbed from 0.298 to 0.401, and U2 from 0.461 to 0.582, showing stable growth overall. In 2020, U1 reached a temporary peak of 0.447, while U2 experienced minor fluctuations due to industry transformation, but the overall upward trend persisted. Hebei's U1 rose from 0.024 to 0.154, and U2 increased from 0.162 to 0.287. Although the overall levels were relatively low, the growth rates were substantial. The sharp decline in Hebei's U1 in 2020 reflected its vulnerability to external pandemic impacts and weak infrastructure, indicating the need for further digitalization efforts. Overall, the development of digital new quality productivity exhibited more pronounced fluctuations compared to the logistics industry's high-quality development. Notably, Hebei's index showed a significant year-on-year decline in 2021, which disrupted the region's rapid upward trend. In contrast to the steady growth of Beijing and Hebei's logistics sectors, Tianjin's high-quality development index experienced prolonged stagnation and even a decline during the study period.

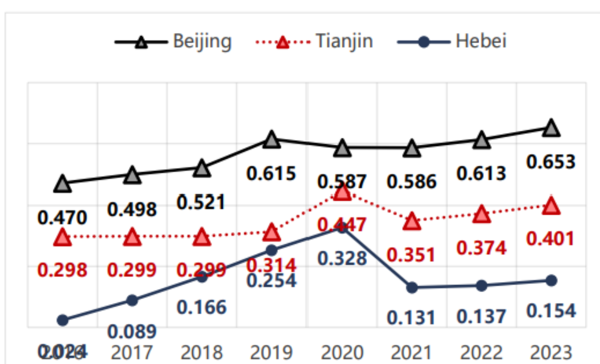

Figure 3. Integrated development level of digital new quality productivity (U1) in three regions

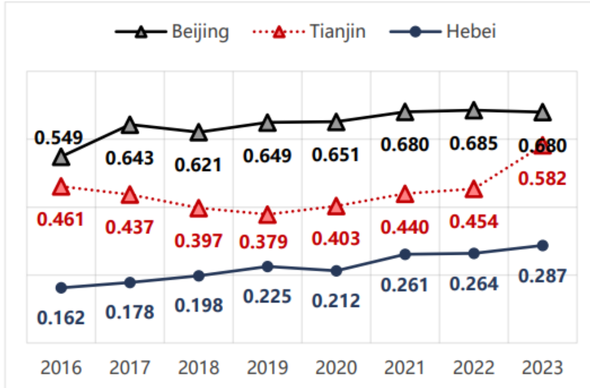

Figure 4. Comprehensive development level of high-quality logistics industry development (U2) in three regions

4.2. Coupling and coordination measure evaluation

4.2.1. Coupling and coordinated measure for overall evaluation

The analysis of the coupling coordination degree (D-value) between digital new-quality productivity and logistics industry development in the Beijing-Tianjin-Hebei region from 2016 to 2023 (see Table 4) reveals a consistent upward trend, with the synergistic relationship between the two systems progressively strengthening. Specifically, the regional D-value increased from 0.361 in 2016 to 0.811 in 2023, reflecting a significant enhancement in coordination levels. This demonstrates the substantial impact of digital new-quality productivity on logistics development, particularly after 2020 when the D-value continued to rise. Overall, the Beijing-Tianjin-Hebei region has transitioned from imbalance to coordination in system integration, with steadily improving development quality. Future efforts should focus on further strengthening digital infrastructure construction and inter-regional resource linkage to consolidate and enhance high-level collaborative development.

Table 4. Coupling coordination degree and type classification of digital new quality productivity and high-quality development of logistics industry in Beijing-Tianjin-Hebei region

	Regional overall		Beijing		Tianjin		Hebei	
	D price	coordination level	D price	coordination level	D price	coordination level	D price	coordination level
2016	0.361	4	0.713	8	0.609	7	0.249	3
2017	0.483	5	0.752	8	0.601	7	0.354	4
2018	0.523	6	0.754	8	0.587	6	0.426	5
2019	0.627	7	0.795	8	0.587	6	0.489	5
2020	0.684	7	0.786	8	0.652	7	0.514	6
2021	0.672	7	0.795	8	0.627	7	0.430	5
2022	0.728	8	0.805	9	0.642	7	0.437	5
2023	0.811	9	0.816	9	0.695	7	0.459	5

4.2.2. Coupling and coordinated measure of regional evaluation

By region, the coupling coordination index (D-value) between digital new-quality productivity and high-quality logistics development in Beijing, Tianjin, and Hebei all showed a fluctuating upward trend, with significant regional disparities (see Table 4). Specifically, Beijing's D-value consistently remained above 0.7, demonstrating minimal fluctuations and indicating a coordinated development phase. Tianjin's D-value ranged between 0.58 and 0.70. In 2018, a temporary decline occurred due to a phased mismatch between the expansion of digital new-quality productivity and adjustments in port logistics structures. After 2020, it rebounded under pandemic pressures and smart port initiatives, showing a gradual U-shaped upward trend, with its coordination level still in a transitional phase. Hebei's D-value was the lowest among the three regions, rising from 0.249 in 2016 to 0.459 in 2023. Although the increase was significant, the overall level remained low. The pandemic's severe impact in 2020 caused a temporary spike followed by a decline, indicating Hebei's weak digital infrastructure, limited high-quality logistics development, insufficient integration of digital elements, and weak synergy between the two systems.

In the spatial distribution of Beijing-Tianjin-Hebei's coordinated development, Beijing maintains its leading position with Tianjin following closely behind, while Hebei lags significantly behind, demonstrating a pronounced regional disparity. Beijing has established itself as a clear innovation leader and radiation hub, whereas Tianjin and Hebei still need to enhance their integration with digital new-quality productivity and logistics development through strengthening digital infrastructure, improving industrial chain coordination, and refining regional integration mechanisms.

4.3. Exploration of driving factors

In order to further explore the main causes of regional differences and evolutionary trends in the coupling and interactive relationship between the new digital productivity and the high-quality development of the logistics industry in Beijing-Tianjin-Hebei, the important driving factors are analyzed and the empirical study is carried out by using the grey correlation degree method.

4.3.1. Analysis of driving factors

4.3.1.1 Government support

Building on the measurement framework proposed by Xue Yang et al. [12], this study establishes the ratio of local fiscal expenditure to regional GDP as a key indicator of government support intensity. Fiscal investment reflects the government's commitment to public services, infrastructure development, and industrial guidance. Substantial fiscal expenditure can effectively optimize the institutional environment for advancing digital new-quality productivity and logistics industry development.

4.3.1.2 Urbanization level

Building on the research of Xue Yang et al. [12], this paper measures urbanization through the proportion of permanent urban residents. Urbanization accelerates the concentration of population, industries, and capital in cities, expands logistics demand and digital service markets, while optimizing logistics node layouts and information flow networks. This creates a foundation for the synergistic evolution of digital new-quality productivity and the logistics industry.

4.3.1.3 Scientific and technological innovation

This study anchors regional innovation capacity through patent application metrics. Following the methodology of Xue Yang et al. [12], we measure regional innovation capability by patent filings. Innovation enhances the endogenous momentum of digital new-quality productivity while driving the logistics industry toward higher value-added segments. Through knowledge spillover and technology diffusion, innovation accelerates digital technology adoption in logistics, strengthening the synergy between the two systems.

4.3.1.4 Infrastructure construction

Based on the study by Wang Jian et al. [14], the ratio of transportation investment to GDP is used as a proxy variable for infrastructure development. Enhancing the transportation network improves logistics efficiency and reduces costs, while providing hardware support for the application of digital technologies in logistics, thereby promoting the deep integration of the two systems.

4.3.1.5 Degree of openness

Based on the framework proposed by Wang Zhen et al. [15], this study measures regional openness through the ratio of total imports and exports to GDP. An open economy accelerates the introduction of advanced technologies, capital, and management expertise, while simultaneously boosting demand for efficient logistics and advancing digital infrastructure and services, thereby enhancing the interaction between the two systems.

In conclusion, the five-dimensional forces—institutional environment, population structure, technological supply, infrastructure, and external environment—work in concert to comprehensively reveal the formation mechanism of the coupling and coordination level between the new digital productivity and the high-quality development of the logistics industry in the Beijing-Tianjin-Hebei region.

4.3.2. Empirical results analysis

Table 5. Grey relational degree of coupling coordination degree with each driving factor

	government support	urbanization level	level of scientific and technological innovation	infrastructure construction	Degree of openness
Beijing	0.668	0.903	0.680	0.889	0.772
Tianjin	0.773	0.968	0.574	0.842	0.863
Hebei	0.505	0.516	0.588	0.534	0.518
regional integration	0.528	0.589	0.844	0.621	0.550

The grey relational analysis (Table 5) reveals that the digital new-quality productivity in the Beijing-Tianjin-Hebei region and the logistics industry's high-quality development demonstrate a distinct pattern of coexisting' regional common driving force 'and' differential regional characteristics'.

Within the broader regional context, technological innovation (0.844) and infrastructure development (0.621) serve as the core drivers for coordinated system development, demonstrating the strongest correlation. This highlights the pivotal role of technological breakthroughs and hardware infrastructure in the current phase. Urbanization (0.589), as a key evolutionary force, also shows strong pull effects. Both government support and openness to external markets exhibit correlation values exceeding 0.5, forming indispensable driving forces that provide critical policy guidance and external market conditions for systemic coordination.

Regional analysis reveals distinct patterns in how driving factors influence coupling coordination. Beijing and Tianjin, serving as dual regional development cores, demonstrate a "city-function-driven" development model. Their coordination levels are primarily driven by advanced urbanization (correlation coefficients: 0.903 and 0.968), supported by robust infrastructure (0.889 for Beijing, 0.842 for Tianjin) and high openness (0.772 for Beijing, 0.863 for Tianjin). In contrast, Hebei's coordinated development relies more on technological innovation (0.588), infrastructure (0.534), and openness (0.518), with urbanization (0.516) and government support (0.505) also playing significant roles. This indicates Hebei is achieving leapfrog development through enhanced technological innovation, infrastructure upgrades, and coordinated openness, urbanization, and government support. Overall, the Beijing-Tianjin-Hebei region has established a diversified driving framework, offering multiple pathways for complementary advantages and functional integration in regional collaboration.

5. Conclusion and policy recommendation

5.1. Conclusion

This study investigates the coupling coordination mechanism between digital new-quality productivity and high-quality development in the logistics industry. We establish comprehensive evaluation systems for both dimensions and conduct empirical measurements of their coupling coordination degree in the Beijing-Tianjin-Hebei region from 2016 to 2023. Using the grey relational analysis model, we further examine the driving factors influencing the regional coupling coordination level. The research yields the following key findings:

1) The Beijing-Tianjin-Hebei region demonstrates steady progress in digital productivity and high-quality logistics development, though regional disparities remain pronounced. Beijing leads in digital technology adoption, innovation capacity, and logistics advancement, fostering synergistic growth. Tianjin maintains balanced progress across both systems with continuous improvements. Hebei's development lags behind, constrained by weak digital economy foundations and insufficient innovation investment, which limits its logistics sector's high-quality development. The region exhibits a clear "Beijing leads—Tianjin progresses steadily—Hebei lags" gradient pattern, highlighting significant differences in integration depth and development pace.

2) The integration and coordination between digital new-quality productivity and the logistics industry in the Beijing-Tianjin-Hebei region have shown an overall upward trend, evolving from "mild imbalance" to "good coordination". Regionally, Beijing maintains consistently high coupling levels with minimal fluctuations, Tianjin is transitioning from moderate to high coordination, while Hebei's overall level remains relatively low but demonstrates significant improvement. This indicates that well-developed digital infrastructure, industrial digital transformation, and policy support play a significant role in promoting the coordinated development of these two systems. However, regional coordination gaps still need to be further narrowed.

3) The grey relational analysis reveals that technological innovation and infrastructure development serve as the core drivers for the coordinated growth of the two systems, while urbanization plays a pivotal supporting role. Government support and opening-up policies provide complementary effects in optimizing the external environment. Regionally, Beijing and Tianjin achieve coordinated development through their high urbanization levels, well-developed infrastructure, and open economies, whereas Hebei relies more on technological innovation and infrastructure upgrades to drive its leapfrog development. This demonstrates a regional characteristic of "coexisting common drivers and differentiated pathways".

5.2. Policy recommendation

Based on the above conclusions, the following specific policy recommendations are proposed.

5.2.1. Enhance the comprehensive development level of regions and narrow regional disparities

Beijing should fully leverage its leadership in digital technology and smart logistics to drive coordinated development in Tianjin and Hebei through technology transfer. Tianjin should capitalize on its port and manufacturing strengths to advance logistics digitalization, establishing smart logistics parks and regional supply chain integration platforms. Hebei needs to increase investments in digital infrastructure and logistics networks, enhance innovation platform development and technology transfer capabilities, and gradually narrow the gap in digital productivity and logistics industry development among the three regions.

5.2.2. Strengthening the coupling coordination mechanism to promote the deep integration of the two systems

Optimize regional spatial planning and industrial structures to integrate digital technologies into core logistics processes. Promote the application of artificial intelligence, big data, and cloud computing in transportation, warehousing, and supply chain management, achieving efficient coordination among information flow, capital flow, and logistics. Beijing focuses on innovation-driven smart logistics and digital supply chain systems, while Tianjin strengthens intelligent port development and cross-border logistics infrastructure. Hebei enhances digital infrastructure and regional collaboration with Beijing and Tianjin, elevating the overall integration level of the region.

5.2.3. Focus on key drivers to promote regional synergy

By leveraging core pillars such as technological innovation and infrastructure development, and through fiscal subsidies, tax incentives, and open policies to strengthen institutional safeguards, a dual-engine mechanism combining technological advancement and infrastructure will be established. Beijing and Tianjin should capitalize on their strengths in innovation and openness to foster high-end industrial clusters, while Hebei must address its infrastructure gaps and innovation deficiencies to enhance urbanization quality and industrial capacity, achieving coordinated progress under the impetus of Beijing and Tianjin.

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