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Digital Economy Development and Urban–Rural Integration in Northeast China: An Empirical Analysis

Shibo Gao [1], Jing Zhang [1], Zuopeng Ma [2], Guolei Zhou [2], Yanjun Liu [1,*] and Yuliang Liu [1]

[1] School of Geographical Sciences, Northeast Normal University, Changchun 130024, China; gaosb530@nenu.edu.cn (S.G.); zhangj888@nenu.edu.cn (J.Z.); liuyl713@nenu.edu.cn (Y.L.)
[2] Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, Changchun 130102, China; mazuopeng@iga.ac.cn (Z.M.); zhouguolei@iga.ac.cn (G.Z.)
* Correspondence: liuyj323@nenu.edu.cn

Abstract: The imbalance between urban and rural development has increased socio-economic challenges. Urban–rural integration has become an important strategy for addressing disparities in development between urban and rural areas in China. The digital economy offers new opportunities to advance urban–rural integration. This study constructs an evaluation index system to assess the degree of urban–rural integration and examines the development of the digital economy in Northeast China from 2010 to 2020. It also studies the impact of the digital economy industry on urban–rural integration. The findings are as follows: (1) The development of the digital economy industry in Northeast China has a significant positive effect on urban–rural integration. (2) The influence of the digital economy industry on urban–rural integration varies across regions, with a stronger effect in areas with a moderate concentration of digital economy industries, non-border regions, and Jilin Province. (3) The facilitative effect of digital economy industries on urban–rural integration diminishes as urban economic levels rise, with two critical thresholds; after surpassing the first threshold, the promoting effect of the digital economy weakens noticeably, and after crossing the second threshold, the effect further declines. Based on these findings, the study offers policy recommendations. The research findings of this paper enrich the theoretical framework for urban–rural integration driven by the digital economy, provide a strong foundation for promoting the digital economy and urban–rural integration in Northeast China, and offer valuable empirical references for other regions exploring urban–rural integration pathways.

Keywords: digital economy industry; urban–rural integration; spatial-temporal pattern; impact effect; Northeast China

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1. Introduction

China's digital economy has developed rapidly, with its scale ranking among the world's highest. According to the *China Internet Development Report (2023)*, the total volume of China's digital economy reached CNY 50.2 trillion in 2023, accounting for nearly 40% of the GDP. The total number of 5G base stations nationwide reached 2.646 million, and the extensive application of digital technologies has become a critical pillar supporting economic and social development. As a key driver of economic development in the new era, the digital economy is reshaping urban–rural relationships and providing strong momentum for integrated urban–rural development [1]. The core of urban–rural integration lies in the free bidirectional flow of factors, and the digital economy plays a crucial role in facilitating this process [2,3]. Digital technologies can help reduce the cost of factor

circulation. With the support of big data, cloud computing, and artificial intelligence, production factors such as labor, capital, land, and information can move more efficiently between urban and rural areas [4]. Supported by policies and technological advancements, the digital economy is expected to further narrow the urban–rural gap, promote resource allocation efficiency, and facilitate comprehensive integration across economic, social, cultural, and other relevant dimensions. This establishes a strong foundation for building a new urban–rural relationship based on shared development [5].

The digital economy industry—characterized by data as a key production factor, digital technology as the core driver, and digital means to restructure production, exchange, distribution, and consumption [6]—features strong spatial penetrability. This allows it to overcome geographical barriers, systematically reshape urban–rural factor flows, and serve as a vital technical bridge for urban–rural integration [5,7]. In Northeast China, digital economy enterprises—including e-commerce, digital technology services, and digital smart agriculture—play multifaceted roles; they optimize rural agricultural product circulation through technical enablement, attract talent return for employment/entrepreneurship via innovative business models, boost rural tourism through digital scenarios, and enhance rural public service efficiency via data integration [8–10].

Urban–rural integration, as a strategic approach to addressing the imbalances and inadequacies in urban–rural development, exhibits marked differentiation in its implementation pathways due to variations in regional economic development stages, resource endowments, and policy environments [1]. Current research on digital economy and urban–rural integration primarily focuses on economically developed regions with mature digital technology applications, while academic inquiries into areas with relatively lagging digital economic development and unique economic-geographical attributes remain relatively scarce [11]. Compared with developed eastern regions, the digital economy industry in Northeast China started later and demonstrates distinct regional characteristics in its development model. As a traditional industrial hub and core agricultural region in China, Northeast China possesses distinct resource endowments, industrial foundations, and urban–rural structural features. It has long faced structural challenges such as a prominent urban–rural dual structure, outflow of factors (resources and population), and an evolution trajectory of urban–rural relations that significantly deviates from conventional development paths. This study selects Northeast China as its research area, aiming to explore how the digital economy drives urban–rural integration within its specific economic, social, and cultural context by analyzing the spatiotemporal pattern evolution of the digital economy in the region. Such an investigation not only provides empirical support for refining the theoretical framework of digital economy-enabled urban–rural integration but also offers practical references for resource-based economic regions and traditional agricultural areas to explore suitable pathways for integrating digital economy and urban–rural development.

Previous research provides a strong theoretical foundation for this study. However, a review of the literature on urban–rural integration reveals the absence of a unified framework for measuring urban–rural integration levels. While numerous studies have examined the impact of the digital economy on urban–rural income disparities, rural revitalization, and rural residents' income from various perspectives [12,13], the specific mechanisms through which the digital economy influences urban–rural integration remain insufficiently explored. In particular, the effects of digital economy industry development on urban–rural integration within specific economic regions have not been systematically analyzed. As a traditional industrial base and major agricultural region in China, Northeast China possesses unique resource endowments and an industrial foundation. However, it has long faced prominent issues such as a stark urban–rural dual structure, resource depletion, and population outflow, which differ significantly from the conventional evolutionary

path of urban–rural relations [14]. Studying the relationship between the digital economy and urban–rural integration in Northeast China not only provides support for the development of its digital economy and urban–rural integration but also helps deepen the understanding of the regional disparities and dynamic characteristics of urban–rural integration. Additionally, it offers new perspectives on the applicability of urban–rural integration theories in specific regions. This study measures urban–rural integration across 34 cities in Northeast China from 2010 to 2020 and seeks to address the following research questions: (1) Has the digital economy industry in Northeast China contributed to urban–rural integration? (2) Do different regions of the digital economy have varying impacts on urban–rural integration? (3) Is there any change in the impact of the digital economy industry on urban–rural integration?

This study makes the following three key contributions: (1) It examines the impact of the digital economy industry on urban–rural integration in Northeast China. (2) Through empirical analysis, it investigates regional variations and threshold effects in the digital economy industry's influence on urban–rural integration. (3) Based on the findings, it provides policy recommendations to foster urban–rural integration in Northeast China.

The rest of the paper is organized as follows: Section 2 reviews and synthesizes the relevant literature. Section 3 outlines the research design. Section 4 examines the spatiotemporal evolution patterns and presents the results of the threshold model. Section 5 discusses the findings, explores policy implications, and identifies the study's limitations. Section 6 concludes the study.

2. Literature Review and Research Hypotheses

The concept of urban–rural integration originates from Western theories on urban–rural relationships. It refers to the process of dissolving the urban–rural divide through spatial restructuring, factor flows, and institutional innovation, ultimately forming an interconnected system characterized by functional complementarity and cultural exchange [15–17]. In the field of urban–rural integration, scholars have proposed many relevant theories, including "regional networks", "urban-rural dual structure", "urban bias", and "coordinated urban-rural development" [18–21]. For measuring the level of urban–rural integration development, scholars generally adopt a comprehensive evaluation research paradigm, constructing evaluation index systems that cover aspects such as population integration, spatial integration, economic integration, social integration, and ecological integration. Research on urban–rural integration development is conducted based on factors such as factor mobility, resource allocation, and land use. Methods like global principal component analysis, exploratory spatial analysis, and kernel density estimation are applied to specific studies [22–24].

The term "digital economy", first introduced by Don Tapscott, was initially equated with the internet economy and defined by early scholars as an economic phenomenon driven by networked information exchange [7]. Over time, the concept has evolved significantly. Today, the digital economy is recognized as a new economic paradigm, with data as a key production factor, digital technology as its core driver, and the internet as a critical platform [25]. Since 2016, research has increasingly focused on the economic functions of digital technologies and their transformative impact on production relations [26]. The digital economy has a positive impact on urban economic growth through means such as improving productivity [27] and reducing production costs [28,29]. Additionally, scholars have also found that the digital economy can increase employment by expanding the market scale [30] and promoting entrepreneurial activities and commercial innovation [31–33]. The digital economy has also transformed trade models—such as cross-border trade and e-commerce—which can effectively improve trade quality and the domestic value-added

rate [31,34], while accelerating the operational efficiency of the financial services industry [35–37].

As an emerging economic model, the digital economy is transforming urban–rural integration at an unprecedented pace and scale. Scholars generally agree that it plays a significant role in advancing urban–rural integration [38]. However, perspectives differ regarding the specific pathways through which the digital economy drives this process, with research primarily focusing on efficiency enhancement, structural optimization, and resource sharing. In terms of efficiency, digital technologies lower market entry barriers, enabling the free flow of rural labor, land, urban capital, and technology across broader markets [38–40]. Regarding structural optimization, the digital economy blurs the boundaries between urban and rural industries, enabling industrial upgrading, bidirectional factor flows, spatial restructuring, and improved allocation of public goods. The integration of primary, secondary, and tertiary industries has also fostered new economic sectors, revitalizing both urban and rural economies [41,42]. In terms of resource sharing, the digital economy leverages advanced information and communication technologies to eliminate information barriers between urban and rural areas. Platforms such as the internet, big data, and AI-driven algorithms enhance information exchange, enabling more precise matching and coordinated development of urban and rural resources [38,43]. Based on this analysis, the following hypothesis is proposed:

Hypothesis 1: The digital economy industry in Northeast China promotes integrated urban–rural development.

By breaking down urban–rural barriers, the digital economy accelerates the flow of production factors between urban and rural areas, thereby advancing urban–rural integration. However, regional disparities in economic development and socio-cultural conditions give rise to diverse digital economy models, resulting in varying levels of urban–rural integration across different regions. As a result, the impact of the digital economy on urban–rural integration exhibits significant regional heterogeneity. For instance, Zhou et al. [11] found that in the lower reaches of the Yellow River Basin, the digital economy has a more pronounced impact on urban–rural integration compared to the upper and middle reaches. Similarly, Zhang et al. [1] demonstrated that the digital economy's impact is stronger in large cities than in small and medium-sized cities. As a traditional industrial base, Northeast China is characterized by diverse resource endowments and socio-economic conditions, leading to variations in the development stages of both the digital economy and urban–rural integration across the region. Building on these insights, the following hypothesis is proposed:

Hypothesis 2: The impact of the digital economy on urban–rural integration in Northeast China exhibits regional heterogeneity.

The digital economy is a high-tech, labor-intensive industry. Regions with higher economic levels generally have abundant resources and dense markets, which foster economies of scale and create more favorable conditions for digital economy development [44]. Economically advanced cities also benefit from more mature social systems and stronger public service capabilities. Greater administrative resources enable these cities to take the lead in removing institutional barriers, such as household registration (hukou) restrictions and land use policies, that hinder factor mobility, thereby accelerating urban–rural integration [45]. As urban economic conditions improve, the relationship between digital economy development and urban–rural integration evolves, leading to variations in the digital economy's impact. For instance, Xin et al. [46] found that in Zhejiang Province, this impact

exhibits threshold effects—when a city's per capita GDP exceeds CNY 82,985, the digital economy's promoting effect weakens. Similarly, Zhang et al. [1] empirically demonstrated that in cities with a per capita GDP exceeding CNY 100,000, the digital economy's impact on urban–rural integration is stronger compared to cities below this threshold. Building on these findings, the following hypothesis is proposed:

Hypothesis 3: The impact of the digital economy on urban–rural integration in Northeast China exhibits threshold effects.

Scholars at home and abroad have conducted a series of theoretical and empirical studies on the measurement of the digital economy, its driving factors and mechanisms, and its impact effects [47,48]; the measurement of urban–rural integration, its driving mechanisms, and regulatory research [14,48]; and how the digital economy drives urban–rural integration [1,11]. These studies have yielded certain achievements, laying the foundation for this research. However, some limitations remain, as follows:

From a theoretical perspective, the existing research has mainly focused on the role of the digital economy in driving rural economic growth from an economic standpoint [49], while studies on the impact of the digital economy on urban–rural integration from a geographical perspective are relatively insufficient. They overlook regional disparities and do not extensively explore the evolutionary processes, driving mechanisms, and impact effects of the research objects across different spatial scales. Based on this, this paper builds on the theoretical connotations of the digital economy industry, explores the development characteristics and driving mechanisms of the digital economy industry in different regions, summarizes the regional differences in how digital economy development empowers urban–rural integration from the multidimensional perspectives of an urban–rural economy, society, space, and ecology, proposes regulatory measures for urban–rural integration in the context of rapid digital economy development, and thereby constructs a geographical theoretical research framework for the digital economy's empowerment of urban–rural integration.

From a research perspective, due to the differences between China's national conditions and those of Western countries, many foreign research results are constructed within the context of Western countries [35–37]. Moreover, given China's vast territory, there are significant differences in natural environments, resource endowments, economic levels, and social development among regions, meaning that existing domestic studies cannot fully support research on numerous regions. Most domestic research on the digital economy focuses on regions with rapid digital economy development [11], such as the Yangtze River Delta and Pearl River Delta, while research on other regions is relatively weak. As an old industrial base, Northeast China has many areas where heavy industry dominates, facing difficulties in industrial transformation and the slow development of the digital economy industry, making it highly representative—one of the starting points of this research. The research framework of this article is shown in Figure 1.

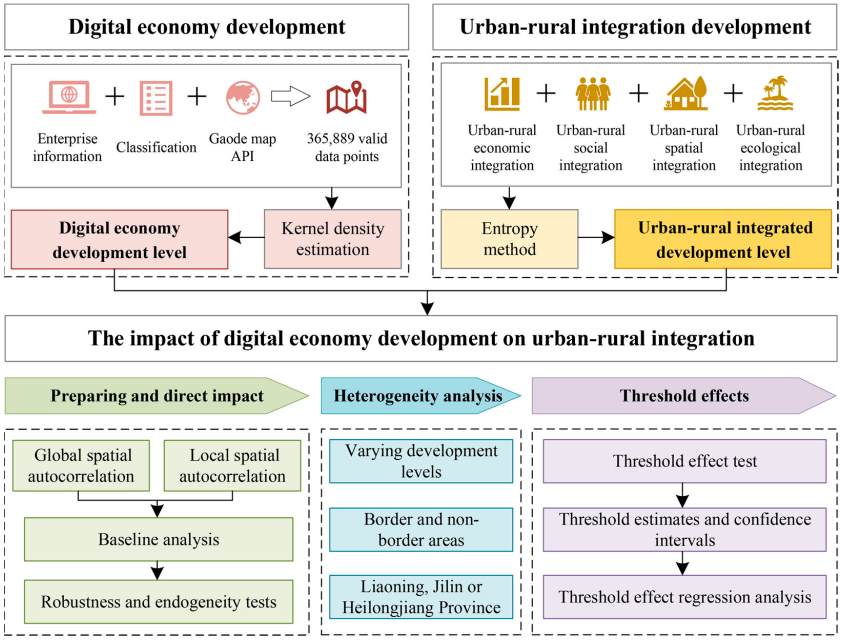


Figure 1. Research framework diagram for the impact of the digital economy industry on urban–rural integration.

3. Research Design

3.1. Study Area

According to the 2011 regional classification by the National Bureau of Statistics of China, the northeastern region comprises the Heilongjiang, Jilin, and Liaoning Provinces. This study focuses on these three provinces (Figure 2), covering 34 prefecture-level cities. However, the Yanbian Korean Autonomous Prefecture and Daxing'anling Prefecture are excluded from the analysis due to data limitations.

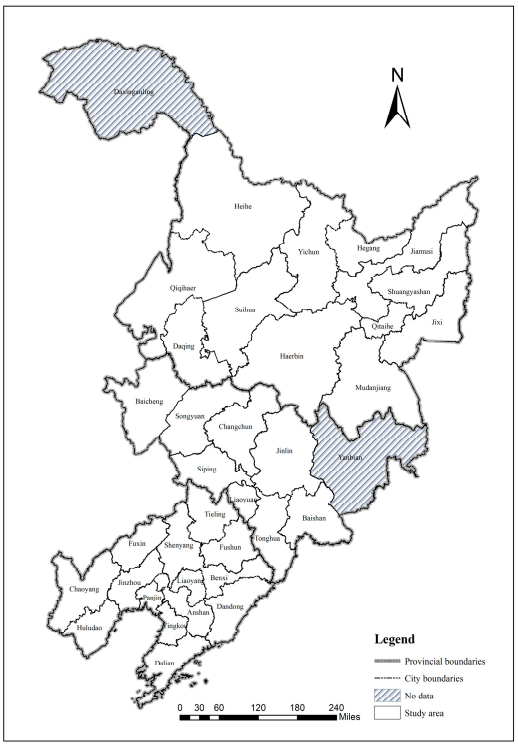


Figure 2. Study area.

3.2. Methods

3.2.1. Measurement of Digital Economy Development Level

To assess the development of the digital economy industry in Northeast China, this study builds on existing research and applies the kernel density estimation (KDE) method to measure the industry's spatial agglomeration across prefecture-level cities in the region [50].

KDE is a widely used non-parametric method for estimating data distribution characteristics based on sample points. In spatial analysis, KDE employs a kernel function to assign weights that decrease as the spatial distance increases. This approach enables a more precise identification of hotspot distributions and spatial agglomeration patterns in the digital economy industry, leveraging enterprise location data. The calculation formula is as follows:

$$f_n(x) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{x - x_i}{h}\right) \quad (1)$$

where $K(z)$ represents the kernel function, h denotes the bandwidth (search radius), n indicates the number of known enterprise location points within the search radius, and $(x\text{-}x_i)$ represents the distance between enterprise x and enterprise x_i.

A higher $f_n(x)$ value indicates a greater degree of digital economy agglomeration, reflecting a higher level of digital economy development in the corresponding city.

3.2.2. Measurement of Rural–Urban Integration Development Level

Urban–rural integrated development is a complex, systemic process involving multiple stakeholders, including residents, governments, and enterprises, as well as various production sectors such as agriculture, industry, and services. It encompasses multiple dimensions across both public and non-public service domains [51]. This study evaluates urban–rural integration across four key dimensions: economic, social, spatial, and ecological, with a total of 14 indicators. Economic integration is assessed using three indicators: industrial upgrading, fiscal support for agriculture, and agricultural modernization [22]. The industrial upgrading indicator reflects the rural industry's capacity to transform from traditional agriculture to modern agriculture, agricultural product processing, and rural service industries, as well as the radiation-driven effect of urban industries on rural areas, embodying the complementarity between urban and rural industries. Governments can directly influence the potential for rural economic development through fiscal investment; adequate financial support can narrow the gap in the allocation of urban–rural production factors and enhance the resilience of agriculture to risks. The intensity of agricultural fiscal support serves as a policy transmission indicator for governments to promote balanced urban–rural economic development, reflecting its institutional guarantee role. Agricultural modernization directly reflects the degree of improvement in rural productivity; only when agricultural production efficiency aligns with that of urban industry and services can there be better two-way flows of factors such as labor and capital. Social integration is assessed using six indicators: urbanization rate, urban–rural income disparity, employment structure, and the availability of medical, educational, and public cultural services [52]. The urbanization rate measures the scale and speed of rural population agglomeration in cities and towns, serving as an overt indicator of urban–rural social integration. Income disparity, the core contradiction of the urban–rural dual structure, directly affects the fairness of residents' quality of life and development opportunities; narrowing income gaps is one of the ultimate goals of social integration. A reasonable employment structure reflects the refined division of labor between urban and rural economies and the integration of labor markets, helping to avoid structural contradictions such as the coexistence of "labor shortages" and "employment difficulties". Equal access to public services is an important marker of social integration: urban–rural gaps in medical resources, educational resources,

and cultural facilities directly impact residents' quality of life and development capabilities, making them key dimensions for measuring social integration. Spatial integration is evaluated based on three indicators: urban spatial expansion, land urbanization level, and urban transportation network density [7,22]. Moderate spatial expansion can promote the sharing of urban–rural infrastructure and form a "urban-driven rural development" spatial linkage effect. High-efficiency land urbanization reflects the comprehensive planning of urban–rural land use, serving as an institutional innovation indicator for spatial integration. Transportation infrastructure acts as the physical link for the flow of urban–rural factors: a high-density transportation network can reduce the cost of factor circulation and facilitate the two-way flow of talent, capital, and information, serving as a foundational support for spatial integration. Ecological integration is measured using two indicators: the forest coverage rate and investment in agricultural non-point source pollution control [53,54]. The forest coverage rate characterizes the quality of the natural ecological foundation and reflects the level of protection and construction of shared green spaces between urban and rural areas. A high forest coverage rate not only improves the rural living environment but also provides ecological services for cities. The prevention and control of agricultural non-point source pollution addresses issues such as chemical fertilizer, pesticide, and livestock breeding pollution in agricultural production. Controlling such pollution safeguards rural ecological security and prevents the transfer of pollution to cities; government investment in governance demonstrates urban–rural synergy in ecological protection. The entropy method was employed to determine indicator weights within the evaluation system, and the level of urban–rural integration in each region from 2010 to 2020 was calculated. The entropy method has significant advantages in multi-index comprehensive evaluation, with its core value lying in a data-driven objective weighting approach that precisely captures the information differences among indicators [1,55]. This makes it especially suitable for the assessment of complex systems such as urban–rural integration. The results of the entropy method are shown in Table 1.

Table 1. Evaluation indicator system for urban–rural integrated development level in Northeast China.

Dimension Layer	Indicator Layer	Indicator Description	Unit	Attribute	Weight Coefficients.
Urban–Rural Economic Integration	Industrial upgrading	Value-added of Secondary and Tertiary Industries/Value-added of Primary Industry	%	+	13.67%
	Fiscal Support for Agriculture	Total Fiscal Expenditure on Agriculture/Local Fiscal Expenditure	%	+	7.36%
	Agricultural Modernization Level	Total Agricultural Machinery Power/Total Cultivated Land Area	kw/hm^2	+	3.53%
Urban–Rural Social Integration	Urbanization Rate	Urban Population/Total Population at Year-End	%	+	5.20%
	Urban–Rural Income Disparity	Disposable Income of Urban Residents/Disposable Income of Rural Residents	%	–	1.08%
	Employment Structure	Employment in Primary Industry/ Total Employment	%	–	2.26%
	Medical Services	Number of Hospital Beds per 10,000 People in the Downtown/Number of Hospital Beds per 10,000 People in Districts	%	–	0.77%
	Education Services	Student–Teacher Ratio in Primary and Secondary Schools in the Downtown/Student–Teacher Ratio in Districts	%	–	0.81%
	Public Cultural Services	Number of Public Library Collections per 10,000 People in the Downtown/Number of Public Library Collections per 10,000 People in Districts	%	–	0.21%

Table 1. *Cont.*

Dimension Layer	Indicator Layer	Indicator Description	Unit	Attribute	Weight Coefficients.
Urban–Rural Spatial Integration	Urban Spatial Expansion	Total Sown Area of Crops/ Built-up Area	%	+	26.90%
	Land Urbanization Level	Built-up Area/Total Downtown Area	%	+	16.59%
	Urban Transportation Network Density	Total Road Mileage/Urban Construction Land Area	km/km^2	+	3.70%
Urban–Rural Ecological Integration	Forest Coverage Rate	Forest Area/Total Land Area	%	+	7.70%
	Investment in Agricultural Non-Point Source Pollution Control	Agricultural Environmental Protection Expenditure/Local Fiscal Expenditure	%	+	10.22%

3.2.3. Research Methods for Impact and Effect Analysis

1. Spatial autocorrelation analysis

Spatial autocorrelation analysis can measure the associative characteristics of geographic elements in spatial distribution and reveal whether the distribution of spatial variables is related to adjacent variables. This paper uses ArcGIS 10.8 software to conduct spatial autocorrelation analysis, with the formula as follows:

$$I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(x_i - \overline{x})(x_j - \overline{x})}{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}\sum_{i=1}^{n}(x_i - \overline{x})^2} \quad (2)$$

where x_i is the observed value of region i, n represents the total number of samples for a variable, I is the global Moran's I index for the variable, and W_{ij} is the spatial weight matrix. The value range of the Moran's I index is $[-1,1]$; a value less than 0 indicates a negative correlation, greater than 0 indicates a positive correlation, and equal to 0 indicates that the spatial units in the study area are independent of each other. The closer the I value is to 1, the more significant the agglomeration effect of the attribute's spatial distribution; the closer it is to -1, the more prominent the divergent trend in the spatial distribution of the attribute being studied.

2. Threshold Effects Model

The threshold effects model, also known as the threshold regression model, is a nonlinear regression approach used to analyze how the relationship between an explained variable and an explanatory variable changes when the explanatory variable exceeds a certain threshold. This study employs the panel threshold model proposed by Hansen to examine the impact of the digital economy industry on urban–rural integration in Northeast China. The model is formulated as follows:

$$\begin{aligned} UrRu_{it} = \mu_i + \beta_{11} digital_{it} I(q_{it} \le \gamma_1) + \beta_{12} digital_{it} I(\gamma_1 \le q_{it} \le \gamma_2) \\ + \beta_{13} digital_{it} I(q_{it} \ge \gamma_3) + \beta_{14}\theta_{it} + \varepsilon_{it}\# \end{aligned} \quad (3)$$

where $I(\cdot)$ refers to the indicator function, $UrRu$ represents the level of urban–rural integration, digital denotes the agglomeration degree of the digital economy industry, i indicates different cities, t represents the year, q_{it} is the threshold variable, γ signifies the threshold value, and θ represents the control variables.

The indicator function I equals 1 if the threshold condition is met; otherwise, it equals 0.

In addition to the core explanatory variable (digital economy), the level of urban–rural integration is influenced by several control variables, as follows:

(1) Government intervention level

Local governments play a pivotal role in urban–rural integration through their policies, resource allocation, and management services, which exert both direct and indirect influences. For example, prioritizing fiscal expenditures on urban development may accelerate urban economic growth but could also widen the urban–rural gap, thereby hindering urban–rural integration. Conversely, increased investment in rural infrastructure, public services, and agricultural development can help narrow this gap and promote balanced development. Fiscal expenditure directly reflects the government's leading role in resource allocation and public service provision. In this study, the proportion of government fiscal expenditure to GDP serves as a proxy for measuring government intervention [27,56,57]. A higher proportion indicates that the government is exerting greater intensity through fiscal policies to regulate urban–rural economic disparities and promote equal access to public services.

(2) Social security level

The level of social security directly impacts the well-being and financial stability of urban and rural residents, shaping their quality of life and sense of security. A well-developed social security system provides economic support in areas such as pensions, healthcare, and unemployment, reducing financial burdens and enhancing consumer confidence. From the perspective of social equity, ensuring equal access to social security benefits fosters fairness, enhances residents' sense of social identity and belonging, and contributes to a stable social environment for urban–rural integration [14,48]. This study measures the social security level using the proportion of social security and employment expenditures to GDP. This indicator reflects the government's investment in sectors such as elderly care, healthcare, and employment training, and serves as a key factor in narrowing the welfare gap between urban and rural residents and promoting the cross-regional allocation of labor.

(3) Employee wage level

Employee wages serve as a critical indicator of urban–rural economic development and income disparities. In a dual urban–rural economic structure, urban areas typically benefit from greater industrial resources, advanced technologies, and superior infrastructure, enabling higher wages for urban employees. In contrast, rural areas often experience slower industrial development, fewer employment opportunities, and lower wages. This wage gap reflects disparities in economic scale, industrial structure, and labor productivity between urban and rural areas, underscoring persistent economic imbalances [58,59]. This study uses the average employee wage as a proxy for this variable. Wage levels are a direct reflection of labor market efficiency and household income, influencing the employment choices and resource allocation of urban and rural labor.

(4) Household savings level

Household savings reflect the economic capacity of urban and rural residents and play a significant role in integrating urban and rural consumer markets. Urban residents generally have more stable and diverse income sources, including varied employment opportunities, higher wages, and a strong social security system, allowing them to save more after meeting daily expenses. In contrast, rural residents primarily depend on agricultural production and occasional non-agricultural employment, leading to lower and less stable incomes and reduced savings capacity [60]. In this study, household savings are measured using the proportion of year-end urban and rural household savings balances to GDP. The savings rate reflects the surplus of funds among urban residents. High savings can provide financial support for urban–rural infrastructure construction and industrial investment, serving as a bridge between household behavior and urban–rural economic integration.

(5) Financial development level

Financial development plays a decisive role in the allocation of capital between urban and rural areas, thereby affecting the balance of economic development [61–63]. This study measures financial development using the proportion of year-end loan balances of financial institutions to GDP. Using the proportion of the indicator in GDP can eliminate the impact of the overall economic scale, measure the efficiency of financial resource allocation, and serve as a key indicator for evaluating how the digital economy promotes urban–rural capital flow through inclusive finance.

Based on existing research [36], this study selects per capita regional GDP as an indicator of regional economic development and uses it as the threshold variable to test for threshold effects.

3.3. Data Sources

3.3.1. Enterprise Big Data

The data for this study were obtained from the Tianyancha website (https://www.tianyancha.com/ (accessed on 15 May 2023)), which provides enterprise information such as name, registered capital, type, address, industry, and business scope. Following the Statistical Classification of the *Digital Economy and Its Core Industries (2021)* issued by the National Bureau of Statistics, the dataset was filtered to include only digital economy enterprises that were operational, active, relocated, or had registered capital exceeding CNY 1 million. The data cutoff date was set as December 2020. Enterprise addresses were geocoded using the Gaode Map API, which provided precise latitude and longitude coordinates through reverse geocoding. After removing entries that were unresolved or incorrectly decoded, a total of 365,889 valid data points were retained for analysis.

3.3.2. Socio-Economic Statistical Data

The data for the urban–rural integration evaluation index system were sourced from publicly available statistical sources, including the *China City Statistical Yearbook* (2010–2020), *Heilongjiang Statistical Yearbook* (2010–2020), *Jilin Statistical Yearbook* (2010–2020), *Liaoning Statistical Yearbook* (2010–2020), statistical bulletins on national economic and social development of prefecture-level cities, local yearbooks, and provincial natural resource bulletins. For missing data in certain years, interpolation was performed using the ARIMA model and multiple imputation methods, based on the available data.

4. Results

4.1. Spatiotemporal Patterns of the Digital Economy Industry and Urban–Rural Integration Development in Northeast China

The spatial distribution of the digital economy industry and urban–rural integration development levels in Northeast China for 2010, 2015, and 2020 were mapped using ArcGIS software. Figure 3 depicts the temporal and spatial evolution of the digital economy over the study period. The average development level of the digital economy increased from 0.109 in 2010 to 0.247 in 2015, and further to 0.645 in 2020, reflecting a steady growth trend. The number of regions with high development levels also showed a gradual increase. The digital economy in Northeast China exhibited significant agglomeration, with enterprises predominantly clustered in capital cities and economically advanced areas, forming a distinct “core-periphery” spatial pattern.

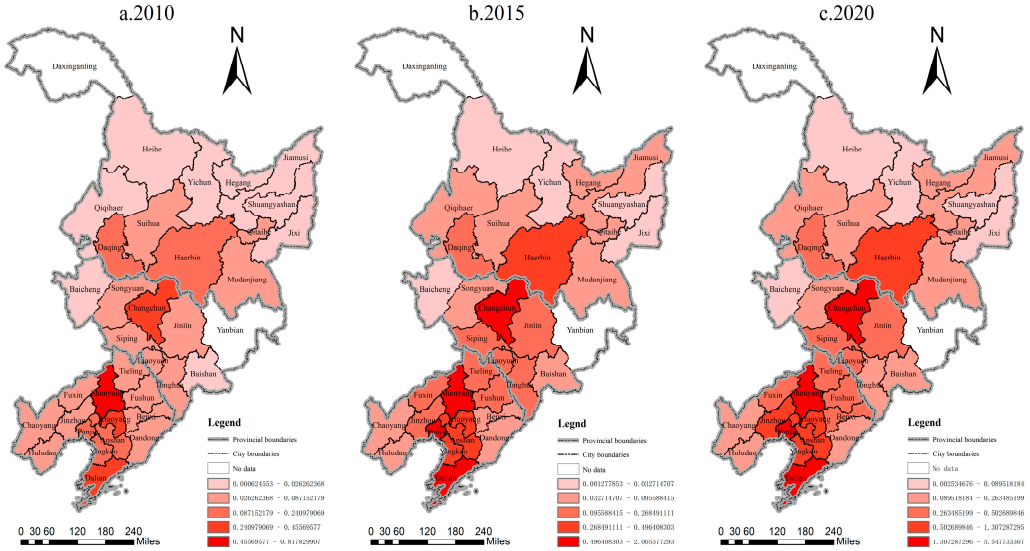


Figure 3. Spatial pattern evolution of the digital economy industry in Northeast China.

Figure 4 depicts the spatiotemporal evolution of urban–rural integrated development levels throughout the study period. The average urban–rural integration level increased from 0.264 in 2010 to 0.267 in 2015, and further to 0.279 in 2020, indicating a consistent upward trend. However, significant regional disparities in urban–rural integration levels are evident across Northeast China. Notably, the western regions exhibit higher integration levels compared to the eastern regions. High-value urban–rural integration zones are predominantly concentrated in the northern Heilongjiang and southern Liaoning Provinces. From 2010 to 2020, cities such as Shenyang, Dalian, Changchun, Heihe, and Suihua consistently maintained high integration levels. In contrast, lower-value areas are primarily found in Hegang, Jiamusi, Shuangyashan, Jixi, Chaoyang, Huludao, and Jinzhou. The specific details of each variable are shown in Table 2.

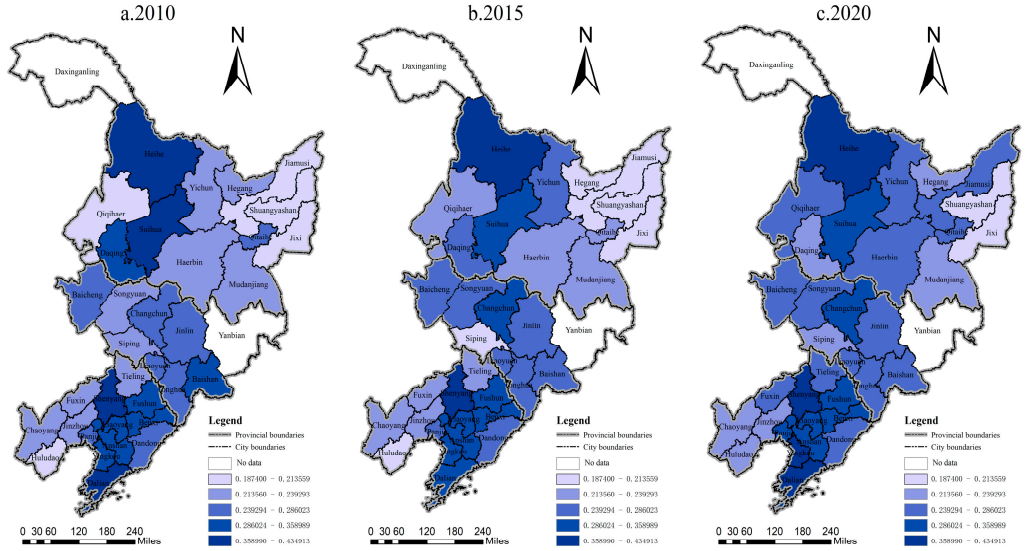


Figure 4. Spatial pattern evolution of the urban–rural integrated development level in Northeast China.

Table 2. Descriptive statistics of variables.

Variable	Variable Description	Mean	Std. Dev.	Min	Max	Sample Size
UrRu	Urban–Rural Integrated Development Level	0.271691	0.058414	0.469157	0.184543	374
digital	Digital Economy Industry Level	0.304423	0.603904	5.547733	0.002682	374
gov	Government Intervention Level	0.002323	0.001088	0.006754	0.000353	374
soc	Social Security Level	0.000477	0.000284	0.002069	0.00005355	374
wag	Employee Wage Level	48,152.7265	15,842.0035	100,781	15,986.25	374
sav	Household Savings Level	1.035	0.5620	3.3488	0.1322	374
fin	Financial Development Level	1.0188	0.5054	2.8686	0.2469	374

4.2. Spatial Autocorrelation Analysis

By comparing the evolution of the spatial patterns of the digital economy industry and the level of urban–rural integration development, a noticeable spatial overlap between the two is evident, indicating a potential strong correlation. Using ArcGIS software and taking Euclidean distance as the instrumental variable, a spatial autocorrelation analysis was conducted on the digital economy industry and urban–rural integration development level in Northeast China. The analysis results are shown in Table 3. The *p*-values for the digital economy industry and urban–rural integration development level passed the significance test, confirming a significant spatial correlation between them. The regions in Northeast China with similar levels of digital economy industry and urban–rural integration development exhibit a clustering trend.

Table 3. Spatial autocorrelation results.

Years	Digital Economy Industry		Urban–Rural Integration	
	Moran's *I*	Z	Moran's *I*	Z
2010	0.053 *	1.688	0.162 **	2.163
2015	0.047 *	1.845	0.172 **	2.311
2020	0.042 *	1.723	0.128 *	1.798

*, **, and *** indicate significance at the 10%, 5%, and 1% confidence levels, respectively.

4.3. Baseline Analysis

This study employs a linear regression model as the baseline analysis to examine the impact of the digital economy industry on urban–rural integration in Northeast China. The results of the baseline regression are presented in Table 4. Column (1) shows the estimation results without control variables. At the 1% significance level, the regression coefficient for the digital economy (digital) is 0.049, which is both positive and statistically significant. This suggests that the digital economy industry in Northeast China significantly contributes to urban–rural integration. When control variables are included, the coefficient for the digital economy remains significantly positive at the 1% level, suggesting that its positive influence on urban–rural integration persists even when accounting for various real-world factors. Among the five control variables, the government intervention level is positively correlated with urban–rural integration at the 1% significance level, while the employee wage level shows a negative correlation at the 10% significance level. The baseline analysis provides preliminary support for Hypothesis 1, which posits that the digital economy industry in Northeast China promotes urban–rural integration.

Table 4. Results of baseline analysis.

Variable	(1)	(2)	(3)	(4)	(5)	(6)
digital	0.049 ***	0.040 ***	0.042 ***	0.043 ***	0.047 ***	0.047 ***
	(0.004)	(0.005)	(0.005)	(0.005)	(0.006)	(0.006)
gov		0.014 ***	0.029 ***	0.025 **	0.035 ***	0.037 ***
		(0.005)	(0.010)	(0.010)	(0.012)	(0.012)
soc			−0.016 *	−0.006	−0.004	0.000
			(0.009)	(0.010)	(0.010)	(0.011)
wag				−0.023 **	−0.022 *	−0.020 *
				(0.011)	(0.011)	(0.011)
sav					−0.010	−0.006
					(0.006)	(0.008)
fin						−0.011
						(0.011)
cons	0.257 ***	0.123 **	0.107 **	0.308 ***	0.330 ***	0.368 ***
	(0.003)		(0.050)	(0.107)	(0.107)	(0.114)
N	374	374	374	374	374	374
R^2	0.254	0.269	0.275	0.284	0.289	

*, **, and *** indicate significance at the 10%, 5%, and 1% confidence levels, respectively.

4.4. Robustness and Endogeneity Tests

To ensure the robustness and reliability of the findings, tests for robustness and endogeneity were performed to assess whether the results are sensitive to variations in model specifications, variable selection, and sample scope.

4.4.1. Replacing the Explained Variable

To test the robustness of the results, the explained variable was replaced. Given the potential lagged effect of the digital economy on urban–rural integration, the level of urban–rural integration was replaced with its value in the following period. As shown in Column (1) of Table 5, the results remain consistent with the original findings, with the digital economy continuing to have a significant positive effect on urban–rural integration at the 1% level.

Table 5. Results of robustness tests.

Variable	(1)	(2)	(3)	(4)
digital	0.049 ***	0.059 ***	0.047 ***	0.048 ***
	(0.006)	(0.011)	(0.129)	(0.006)
gov	0.027 **	0.044 ***	0.031 **	0.028 **
	(0.013)	(0.012)	(0.012)	(0.013)
soc	0.005	−0.002	0.003	0.008
	(0.012)	(0.012)	(0.012)	(0.013)
wag	−0.024	−0.023 *	−0.023 *	−0.029 **
	(0.013)	(0.012)	(0.013)	(0.015)
sav	−0.008	−0.004	−0.005	−0.005
	(0.008)	(0.008)	(0.008)	(0.008)
fin	−0.006	−0.013	−0.010	−0.012
	(0.012)	(0.011)	(0.012)	(0.012)
cons	0.417 ***	0.357 ***	0.409 ***	0.498 ***
	(0.131)	(0.125)	(0.129)	(0.149)
N	340	341	340	306
R^2	0.294	0.179	0.295	0.308

*, **, and *** indicate significance at the 10%, 5%, and 1% confidence levels, respectively.

4.4.2. Excluding Capital Cities

Since Shenyang, Changchun, and Harbin have higher administrative levels than other regions, their inclusion may introduce bias. To address this, these three cities were excluded from the analysis for robustness testing. The results in Column (2) of Table 5 demonstrate that the digital economy industry remains significantly positive at the 1% level, confirming its positive impact on urban–rural integration in Northeast China.

4.4.3. Instrumental Variable Approach

To address potential endogeneity issues, an instrumental variable approach was applied. The development level of the digital economy industry, lagged by one and two periods, was used as an instrument, and the two-stage least squares (2SLS) method was employed for endogeneity testing. As shown in Columns (3) and (4) of Table 5, the estimated coefficient of the digital economy industry remains positive and statistically significant at the 1% level, confirming the robustness of the earlier findings.

4.5. Heterogeneity Analysis

As outlined in Section 4.1, the development of the digital economy in Northeast China shows considerable regional variation, with notable disparities between certain areas. To further investigate the impact of the digital economy on urban–rural integration, a heterogeneity analysis was conducted to examine its effects across regions with varying development levels. Prefecture-level cities in Northeast China were classified into high, medium, and low agglomeration categories using the natural breaks method, based on the development of the digital economy industry. Ordinary least squares (OLS) regression was employed for the regional heterogeneity analysis, and the results are presented in Columns (1), (2), and (3) of Table 6. The findings demonstrate that the digital economy positively influences urban–rural integration, with high-agglomeration regions showing significance at the 10% level, and medium- and low-agglomeration regions at the 1% level. The regression coefficients suggest that the effect is stronger in medium-agglomeration regions.

Table 6. Heterogeneity analysis based on different development levels of the digital economy industry.

Variable	(1)	(2)	(3)
digital	0.011 *	0.177 ***	0.129 ***
	(0.006)	(0.042)	(0.049)
gov	−0.009	−0.069 ***	0.068 ***
	(0.035)	(0.037)	(0.014)
soc	0.065 **	0.074 **	−0.008
	(0.027)	(0.035)	(0.013)
wag	−0.123 ***	−0.183 ***	−0.007
	(0.024)	(0.05)	(0.014)
sav	−0.053 *	−0.035	−0.024 **
	(0.029)	(0.027)	(0.009)
fin	0.11 *	0.041	−0.027 **
	(0.058)	(0.032)	(0.012)
cons	0.225	2.154 ***	0.518 ***
	(0.348)	(0.488)	(0.155)
N	44	55	275
R^2	0.875	0.459	0.113

*, **, and *** indicate significance at the 10%, 5%, and 1% confidence levels, respectively.

The study also categorized the research units into border and non-border areas. The results, shown in Columns (1) and (2) of Table 7, indicate that the digital economy industry does not have a significant impact on border areas but has a significant positive effect on

non-border areas at the 1% level. Additionally, the research units were analyzed by province (Liaoning, Jilin, and Heilongjiang), with the results presented in Columns (3), (4), and (5) of Table 7. The digital economy industry in the Liaoning and Jilin Provinces has a significant positive effect on urban–rural integration, with Jilin's coefficient (0.038) surpassing that of Liaoning (0.022). In contrast, the digital economy industry in Heilongjiang Province does not have a significant impact on urban–rural integration. These heterogeneity test results offer empirical support for Hypothesis 2, indicating that the digital economy's influence on urban–rural integration in Northeast China differs across regions.

Table 7. Heterogeneity of regression results based on geographic location.

Variable	(1)	(2)	(3)	(4)	(5)
digital	−0.192	0.044 ***	0.022 ***	0.038 ***	0.072
	(0.161)	(0.005)	(0.006)	(0.008)	(0.051)
gov	0.159 ***	−0.006	−0.043 **	−0.000	0.184 ***
	(0.027)	(0.012)	(0.018)	(0.017)	(0.023)
soc	−0.044 **	0.010	0.041 **	−0.012	−0.063 ***
	(0.022)	(0.012)	(0.018)	(0.013)	(0.018)
wag	0.007	−0.035 ***	−0.076 ***	0.028 ***	0.022
	(0.783)	(0.012)	(0.020)	(0.010)	(0.017)
sav	−0.026 *	0.000	0.046 ***	0.026 **	−0.036 ***
	(0.014)	(0.010)	(0.012)	(0.011)	(0.012)
fin	−0.043 **	0.011	0.001	−0.031 **	−0.078 ***
	(0.019)	(0.014)	(0.014)	(0.013)	(0.026)
cons	0.087	0.443 ***	0.413 **	0.133	0.498 ***
	(0.267)	(0.122)	(0.189)	(0.103)	(0.237)
N	110	264	154	88	132
R^2	0.288	0.387	0.560	0.582	0.363

*, **, and *** indicate significance at the 10%, 5%, and 1% confidence levels, respectively.

4.6. Threshold Effects of the Digital Economy Industry on Urban–Rural Integration in Northeast China

4.6.1. Threshold Effect Test

This study, conducted using StataMP 18 software, investigates whether threshold effects exist in the relationship between the digital economy industry and urban–rural integration in Northeast China. The economic development level is selected as the threshold variable, and Hansen's bootstrap method is used to accurately identify the number of thresholds. The results are summarized in Table 8.

Table 8. Results of threshold effect test.

Threshold Variable	F-Value	*p*-Value	BS Times	Critical Values		
				1%	5%	10%
Single Threshold	7.93	0.6733	300	41.821	36.4776	28.0413
Double Threshold	20.74	0.0633	300	18.9684	23.3904	35.0592
Triple Threshold	7.70	0.7433	300	54.3821	34.5187	26.6234

As presented in Table 8, the single threshold effect does not reach statistical significance at the 10%, 5%, or 1% levels. In contrast, the double threshold effect is significant at the 10% level, while the triple threshold effect does not reach significance at any level. These results suggest that the relationship between the digital economy and urban–rural integration in Northeast China is not linear but instead characterized by significant double threshold effects. This provides empirical support for Hypothesis 3, which proposes that

the impact of the digital economy on urban–rural integration in Northeast China is subject to threshold effects.

4.6.2. Threshold Estimates and Confidence Intervals

To further investigate the threshold characteristics of the digital economy industry's impact on urban–rural integration, the threshold estimates and their corresponding confidence intervals were analyzed after confirming the presence of a double threshold effect. The results are summarized in Table 9.

Table 9. Results of Threshold estimate.

Model	Threshold	Threshold Estimate	95% Confidence Interval
Double Threshold	First Threshold	9.9372	[9.9161, 9.9544]
	Second Threshold	11.1578	[11.1255, 11.2026]

When eco = 9.9372, the per capita GDP is CNY 20,685.74; when eco = 11.1578, the per capita GDP is CNY 70,108.55.

The first threshold is estimated at 9.9372, and the second at 11.1578. These values indicate that the impact of the digital economy on urban–rural integration varies based on regional economic development levels. The regions can be divided into three categories: (1) regions with an economic development level below 9.9372; (2) regions with an economic development level between 9.9372 and 11.1578; (3) regions with an economic development level above 11.1578.

4.6.3. Threshold Effect Regression Results

To further examine the nonlinear impact of the digital economy industry on urban–rural integration, a double threshold regression model was employed. The results are summarized in Table 10.

Table 10. Regression results of the double threshold model.

Variable	Coefficient Estimate	Standard Error	T-Value
gov	6.120021 **	2.727532	2.25
soc	−13.09029	10.80317	−1.21
wag	0.0171868 ***	0.0052269	3.29
sav	−0.0028994	0.0037079	−0.78
fin	−0.0061335	0.0043309	−1.42
Digital × I (eco ≤ 9.9372)	0.5595292 ***	0.1985051	2.82
Digital × I (9.9372 < eco ≤ 11.1578)	0.0209711 ***	0.0047689	4.40
Digital × I (eco > 11.1578)	0.0110146 ***	0.0026738	4.12
Constant	0.0833433	0.527455	1.58
N	374		
R^2	0.2590		

*, **, and *** indicate significance at the 10%, 5%, and 1% confidence levels, respectively. When eco = 9.9372, the per capita GDP is CNY 20,685.74; when eco = 11.1578, the per capita GDP is CNY 70,108.55.

The regression analysis reveals that, at the 1% significance level, the digital economy industry has a significant positive effect on urban–rural integration, suggesting that it promotes urban–rural development in Northeast China. However, this impact is nonlinear. When urban economic development is below the first threshold of 9.9372 (urban per capita GDP < CNY 20,685.74), the regression coefficient is 0.560. As the urban development level falls between the first and second thresholds (20,685.74 < urban per capita GDP < CNY 70,108.55), the coefficient drops to 0.021. Finally, when urban development

exceeds the second threshold of 11.1578 (urban per capita GDP > CNY 70,108.55), the coefficient further declines to 0.011. These findings indicate that as urban economic development increases, the positive effect of the digital economy industry on urban–rural integration diminishes. When the threshold variable crosses the threshold value, the impact of the digital economy industry on urban–rural integration development undergoes a structural change, and the regression coefficients exhibit significant differences across different intervals, indicating that the effect of the digital economy industry on urban–rural integration development in Northeast China is nonlinear.

5. Discussion

5.1. Interpretation of Results

5.1.1. Digital Economy Industry and Urban–Rural Integration in Northeast China

This study evaluates the level of urban–rural integration in prefecture-level cities in Northeast China across four dimensions: economic, social, spatial, and ecological integration. The findings highlight significant regional disparities in urban–rural integration, which may be influenced by factors such as government policy intervention, social security, employee wages, household savings, and financial development [45,64–72]. Several studies have shown that, with government support, the digital economy can overcome spatial boundaries, enabling the flow of resources between urban and rural areas [27,56,57]. By creating employment and entrepreneurial opportunities in rural areas, the digital economy promotes the migration of skilled urban labor to rural industries, thus fostering urban–rural integration [69]. Furthermore, the widespread use of digital inclusive finance eliminates spatial and temporal barriers to financial services, overcoming the limitations of traditional financial products and further contributing to urban–rural integration [65–67].

This study examines the impact of the digital economy industry on urban–rural integration in Northeast China. The baseline results indicate that the digital economy industry positively influences urban–rural integration, consistent with previous research [1,11,70,71]. For instance, Wang [72] found that the digital economy fosters urban–rural integration at the provincial level, while Lei et al. [60] demonstrated that the digital economy accelerates integration by enhancing the digitalization of agricultural production and the networking of agricultural product markets. In other countries, due to different stages of urbanization, many scholars have not linked the digital economy with urban–rural integration, but they have explored the role and impact of the digital economy in urban development. Ofori I K et al. found that the adoption of technologies such as digital communication has contributed to urban development in sub-Saharan Africa [35]. Through empirical research, Mignamissi et al. discovered that the digital divide seriously hinders the development of financial systems in Africa, while countries with leading digital technologies or digital dividends possess relatively developed financial systems, thereby accelerating urban development [36]. Balsmeier et al. confirmed that in Switzerland, the digital economy can promote urban development by influencing employment [33]. This study provides empirical evidence of the relationship between the digital economy industry and urban–rural integration in Northeast China, providing valuable insights into the role of the digital economy in promoting urban–rural integration.

5.1.2. Heterogeneity of the Digital Economy Industry's Impact on Urban–Rural Integration in Northeast China

Building on the baseline analysis, this study further explores the varying impacts of the digital economy industry on urban–rural integration. First, regions with varying levels of digital economy agglomeration show that the positive effect on urban–rural integration is most pronounced in areas with moderate agglomeration. This may occur because regions

with moderate agglomeration can fully utilize the benefits of clustering while avoiding the negative effects of excessive concentration, allowing for more effective technology spillovers between urban and rural areas.

Second, when comparing border and non-border cities, the digital economy industry has a significant positive impact on urban–rural integration in non-border cities, but no such effect is seen in border cities. This disparity can be attributed to the dual constraints of geopolitics and the distinct economic structure in Northeast China's border regions. These areas have traditionally relied on port trade and resource-based industries, creating a reliance on "transit economies". The digital economy faces challenges in adapting to local industries like cross-border trade and logistics, and severe rural depopulation disrupts the sustainability of the digital economy's supply–demand balance. In contrast, non-border cities, with more complete industrial systems and stable factor markets, provide a more favorable environment for integrating digital technologies into agriculture and rural areas [1,73,74].

Finally, when analyzing different provinces, the digital economy industry demonstrates a significant positive impact on urban–rural integration in the Liaoning and Jilin Provinces, with a stronger effect in Jilin Province. In contrast, no significant impact is observed in Heilongjiang Province. This variation is due to differences in how industrial structures and digital transformation strategies align across the three provinces. Jilin, as a core region for national food security, has agricultural digital transformation needs, such as black soil protection and smart farming, that align closely with the digital economy's capabilities. E-commerce platforms and productive services facilitate the exchange of urban and rural resources effectively. Liaoning, leveraging its equipment manufacturing base, focuses on the industrial internet and service extensions to foster urban–rural industrial collaboration. However, Heilongjiang faces challenges due to its resource-based economy, where technological gaps exist between the digital economy and dominant industries such as energy and forestry. Furthermore, special policies in border areas hinder the integration of digital technologies into traditional agricultural systems, weakening the urban–rural connection.

Scholars have also conducted research on related aspects. Zhang et al. explored the heterogeneity of the digital economy's impact on urban–rural integration at the national scale. The results show that its effect is stronger in eastern regions than in central and western regions; significantly higher in non-border areas than in border areas; and more pronounced in large cities with a higher per capita GDP than in small and medium-sized cities [1]. Zhou et al.'s findings indicate that in the lower reaches of the Yellow River Basin, the digital economy has a stronger impact on urban–rural integration than in the middle and upper reaches [11].

5.1.3. Threshold Characteristics of the Digital Economy Industry's Impact Effect on Urban–Rural Integration

This study confirms that the impact of the digital economy industry on urban–rural integration in Northeast China follows a dual threshold pattern. As urban economic levels increase, the positive effect of the digital economy on urban–rural integration gradually weakens, with two distinct threshold points identified. This pattern reflects the phased attenuation mechanism of Northeast China's urban–rural system in response to the digital economy. In the early stages of economic development, the digital economy significantly improves urban–rural integration by addressing infrastructure gaps and facilitating the flow of factors. However, when economic levels surpass the first threshold, structural misalignments arise between the traditional heavy industry system and digital innovation. State-owned enterprises' digital transformation primarily focuses on urban upgrades, creating a disconnect with rural industrial chains. In more advanced stages, beyond the

second threshold, urban economic agglomeration and institutional rigidity concentrate digital resources in high-end urban sectors, while barriers such as the household registration system (hukou) and land policies prevent the diffusion of technological benefits to rural areas. The inertia of Northeast China's "unit system" social organization allows medium-sized cities to maintain collaboration between state-owned enterprises and collective economies. However, as market reforms deepen in high-income areas, the erosion of traditional urban–rural links accelerates, leading to a weakening positive impact of the digital economy on urban–rural integration as urban development increases.

This result is consistent with the conclusions of some scholars. Xin et al. explored the impact of the digital economy on urban–rural integration development in Zhejiang Province, finding that when the urban economic development level is below the threshold value, the digital economy has a strong driving effect on urban–rural integration; once the economic development level exceeds the threshold, its promoting effect on urban–rural integration weakens [46].

5.2. Policy Recommendations

Based on the empirical findings, this study offers the following recommendations:

In terms of economic integration, efforts should prioritize removing data barriers between the industrial internet and agricultural supply chains, aligning the digital transformation of state-owned enterprises with county-level industrial clusters, and developing a "digital technology + food security" ecosystem. These initiatives aim to improve the market-based allocation of urban–rural factors and promote value chain sharing.

For social integration, it is crucial to strengthen the inclusive functions of digital technologies by establishing a digital skills training network that spans urban and rural areas. High-quality educational resources should be extended to rural regions through cloud platforms, and blockchain-based systems for rural collective asset ownership should be developed to protect farmers' rights during the digital transformation.

In terms of spatial integration, priority should be given to the development of intelligent logistics hubs and border digital corridors. The allocation of cold chain big data centers should be optimized to serve grain-producing areas, and a unified urban–rural spatial information management platform should be established to eliminate administrative barriers to the flow of digital economy resources.

For ecological integration, it is crucial to enhance digital protection mechanisms for black soil, create intelligent sensing systems for farmland quality monitoring, and develop agricultural non-point source pollution warning systems. Additionally, integrating ecological product value realization mechanisms with carbon trading digital platforms will support the value transformation and benefit rebalancing of urban–rural ecological resources.

Given the phased attenuation characteristics of the digital economy's impact on urban–rural integration in Northeast China, a tiered policy response system should be developed. For low-income cities, the focus should be on building fundamental digital infrastructure and facilitating factor circulation mechanisms. This includes promoting the digital transformation of the entire agricultural supply chain, bridging urban–rural factor flow gaps through technology diffusion, and enhancing the digital value-added capabilities of county-level specialty industries. For medium-economic-level cities, attention should be directed toward removing institutional barriers, fostering innovative collaboration between the digital transformation of state-owned enterprises and rural industries, and constructing two-way empowerment channels between the industrial internet and agricultural production. For high-economic-level cities, efforts should aim at deepening institutional innovation to establish cross-regional mechanisms for redistributing digital economy benefits, facilitating the reverse flow of high-end factors to rural areas. Key barriers, such as

household registration (hukou) and land systems, which hinder the fair sharing of digital dividends, need to be addressed. Additionally, the computational resources of central cities should be leveraged to strengthen their support for rural revitalization.

Due to data limitations, the study period of this paper is 2010–2020. Although the digital economy has developed rapidly in recent years, the urbanization stages of cities in Northeast China have not undergone substantial changes, and the issue of unbalanced urban–rural development remains. As the digital economy continues to grow rapidly, its attributes—such as breaking through geographical constraints and enhancing the flow of urban–rural resource factors—will be further strengthened, continuing to promote urban–rural integration. Moreover, regional differences will persist due to variations in each city's resource endowments and economic development levels.

5.3. Limitations and Constraints

This study examines the impact of the digital economy industry on urban–rural integration in Northeast China. However, due to limitations in data availability, the selection of control variables may not be comprehensive. The study spans from 2010 to 2020, but it does not distinguish between the long-term and short-term effects of the digital economy on urban–rural integration. Future research could integrate multi-source data to enhance variable selection and employ dynamic models to explore the temporal variations in the digital economy's impact on urban–rural integration. Potential measurement errors and the inability to exclude spatial spillover effects from outside the study area are the methodological limitations of this paper. Additionally, while the research findings can provide some reference for other regions, their applicability is relatively limited for areas with substantial differences in economic development levels and resource endowments.

6. Conclusions

This study first assesses the development levels of the digital economy industry and urban–rural integration in Northeast China, outlining their spatiotemporal evolution from 2010 to 2020. Next, using panel data from 2010 to 2020, regression models are applied to analyze the impact of the digital economy industry on urban–rural integration, exploring the heterogeneity of this effect. Finally, a threshold regression model is applied to investigate the nonlinear characteristics of the digital economy industry's influence on urban–rural integration. The key findings are as follows:

(1) The digital economy industry and urban–rural integration in Northeast China demonstrate significant spatial correlation, with the digital economy positively impacting urban–rural integration.

(2) The effect of the digital economy on urban–rural integration varies regionally. The positive impact is more pronounced in cities with moderate digital economy development, non-border cities, and Jilin Province.

(3) The impact of the digital economy on urban–rural integration exhibits a double threshold effect. As urban economic levels increase, the digital economy's role in promoting urban–rural integration diminishes, with two critical thresholds identified: after crossing the first threshold, the impact weakens notably, and after surpassing the second threshold, the effect further attenuates.

Based on these findings, Northeast China should develop differentiated digital economy strategies, tailored to local conditions such as geographical location, industrial foundation, and economic development level.

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