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The impact of the digital economy on rural industrial revitalization☆

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ABSTRACT

The digital economy significantly influences the development of rural industries in China, playing a vital role in the country's economic and social progress. This study analyzes panel data from 30 Chinese provinces (2011–2021) to explore the digital economy's impact on rural industrial revitalization from a sustainable development perspective. This study finds that the digital economy positively affects rural industrial revitalization, with scientific and technological innovation acting as a positive intermediary. In addition, the impact varies regionally, following a "central > west > east" pattern, with differing effects based on rural employment levels. Furthermore, as scientific and technological innovation capabilities increase, the digital economy's influence on rural industries grows stronger. The digital economy exerts a spatial spillover effect, benefiting local rural industries but negatively impacting neighboring regions' rural industry development. These findings highlight the critical role of the digital economy in the sustainable development and revitalization of rural industries in China.

1. Introduction

China is a leading agricultural producer. Since the reform and opening policies in 1978, rapid industrialization and urbanization have significantly transformed agricultural production, farmer livelihoods, and rural society. However, as Park (1932) noted, many social challenges in the East are rural-related. China faces issues such as a vast population, a weak rural foundation, a poor agricultural base, and a significant urban-rural divide (Liu et al., 2020; Wang et al., 2024a,2024b,2024c). The extensive rural development, low economic efficiency, and serious pollution, exacerbated by the urban-rural dual structure and a city-focused strategy, increasingly hinder the sustainable development of China's economy (Tang and Chen, 2022). Boosting agricultural productivity and farmers' income remains a key concern for the Chinese government (Shen et al., 2022).

To address unbalanced and insufficient rural development, China introduced the "Rural Revitalization" strategy in 2017. Since then, rural industries have grown rapidly, achieving remarkable progress. Industrial development is crucial for promoting future rural development. In 2020, China released the "National Rural Industry Development Plan (2020–2025)", emphasizing rural industry

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development as fundamental to rural revitalization. This comprehensive approach has been vital in transforming China into a strong agricultural country, narrowing the urban-rural gap, and increasing farmers' income. According to the National Bureau of Statistics of China, the added value of agriculture and allied sectors in 2022 was 19,569.2 billion yuan, accounting for 16.24 % of the GDP, up 0.19 percentage points from the previous year. In 2023, the per capita disposable income of urban and rural inhabitants was 51,821 yuan and 21,691 yuan respectively, reducing the income disparity to 2.39 times, 0.06 less than in 2022, indicating a continued decrease in the urban-rural income gap.

In recent years, digital technology has achieved significant breakthroughs and widespread applications, leading to the progressive emergence of the digital economy. By 2023, the scale of China's digital economy exceeded 55 trillion yuan, rapidly penetrating various fields such as environmental protection (Du et al., 2023; Yi et al., 2022; Lee and Wang, 2022; Shahbaz et al., 2024), financial development (Du et al., 2023), government governance (Zhao et al., 2023), corporate influence (Lee et al., 2023; Heredia et al., 2022; Gao et al., 2023; Zhang et al., 2023a,2023b,2023c; Huo and Wang, 2022), urban development (Wang et al., 2024a,2024b,2024c), and rural security (Wang et al., 2024a,2024b,2024c). In rural areas, government policies such as the "Digital Rural Development Action Plan (2022–2025)" and the "Digital Rural Construction Guidelines 2.0" have fostered a favorable environment for rural industry development. Digital information and technology have increasingly been applied to agricultural production and distribution. In 2022, China's rural e-commerce retail sales reached 2.17 trillion yuan, and the number of Taobao villages grew from 2118 in 2017–7780 in 2022. This demonstrates the digital economy's transformative impact on the rural economic structure, driving the transformation and upgrading of rural sectors (Zhang et al., 2023a,2023b,2023c). The digital economy is increasingly seen as a key driver for the revitalization and sustainable development of rural industries. Tang and Chen (2022) explored the relationship between agricultural digitalization and high-quality agricultural development. Zhang et al. (2023a),(2023b),(2023c) found that the digital economy has great practical significance for the development of green agriculture. Yang et al. (2024) explained the relationship between the digital economy and sustainable agriculture from the perspective of ecological agricultural technology. Chen and Long (2024) believed that using e-commerce platforms to support agriculture is an innovative approach and emphasized the key role of e-commerce in the sustainable development of rural industries.

Existing research mostly focuses on the impact of the digital economy on agricultural development, leaving plenty of potential for empirical research on how the digital economy drives rural industries. Furthermore, the function of scientific and technological innovation capabilities as a mediating component in this relationship warrants additional investigation. At the same time, the spatial spillover effect of the digital economy on rural industrial revitalization has not yet received widespread attention. This study uses agricultural and rural development data from 30 provinces in China from 2011 to 2021 to explore the relationship between the digital economy and rural industrial revitalization. Theoretically, it enriches research on the digital economy's impact on rural industrial revitalization through mediation effects, heterogeneity, threshold effects, and spatial effects. Practically, it provides scientific guidance for government policy implementation, boosts rural innovation, increases employment opportunities, guides optimal resource allocation between urban and rural areas, and supports the sustainable development of the rural economy.

2. Theoretical analysis and research hypotheses

Rural industries are essential for promoting income growth and development in rural areas. Revitalizing rural industries can enhance the capacity of rural areas to sustain themselves and providing necessary jobs, thereby increasing farmers' income. The digital economy, with its advantages in cross-temporal and spatial information dissemination, data-driven decision-making, low costs, high circulation, advanced technology, and strong penetration, effectively addresses issues such as inefficient allocation of rural production factors, poor market information, and low product added value (Zhao et al., 2023; Guo et al., 2023). Beyond its direct impact on rural industrial development, the digital economy can also indirectly influence regional rural industries by enhancing regional scientific and technological innovation capabilities. According to "Metcalfe's Law," the value of a network increases with the square of the number of its nodes, implying that more extensive networks can have a greater economic and social impact. Therefore, the influence of the digital economy on rural industrial revitalization may exhibit nonlinear characteristics and spatial spillover effects. Although traditional rural development theories or resource dependence theories provide some insights into resource allocation and development paths, they are limited to traditional agricultural production and economic activities and fail to fully explain how technological innovation or informationization factors influence the development of modern rural industries in the context of the digital economy. Sustainable development theory can explain the long-term impact of the digital economy on rural industries in a more comprehensive way, which is consistent with the digital economy's role in promoting rural industry development, particularly in terms of the balance of environmental, social and economic benefits.

2.1. The impact mechanism of the digital economy on rural industrial revitalization

Current research on the digital economy focuses on its role in promoting the urban economy, and the impact of the digital economy on rural industries still needs further discussion. The technological economic paradigm theory underscores that the digital economy is a transformative force, driven by intelligent technology, network connectivity, and data as a pivotal production factor (Goodell et al., 2023a, 2023b; Hunjra et al., 2024). Unlike traditional production elements such as land, labor, and capital, which have fixed use modes and limited value, data's unique properties—replicability, shareability, and low cost—enable profound transformations in rural industries, driving intensification, specialization, greening, integration, and efficiency.

Firstly, the digital economy significantly enhances the intensification of rural industries. The rapid generation and collection of data break through the limitations of traditional resources, allowing for high-quality, efficient agricultural production. Digital

agricultural technology boosts mechanization and large-scale operations, dramatically improving production efficiency, optimizing agricultural models, and increasing product quality and output (Struik and Kuyper, 2017).

Secondly, the digital economy fosters specialization in rural industries. By leveraging rural resource endowments, it enhances labor division and cooperation across various production links, driving industry refinement and differentiation. For instance, rural e-commerce catalyzes online sales, logistics, packaging, and marketing, while farmers' cooperatives offer comprehensive services like sales, processing, transportation, storage, and technical support, promoting specialized production.

Thirdly, the digital economy drives the greening of rural industries. Its inherent low resource consumption and minimal environmental impact make it a powerful driver for green development (Ma and Zhu, 2022). Digitalization reshapes agricultural production and operations, positioning it as a critical force for low-carbon, sustainable agriculture (Xu et al., 2022).

Fourthly, the digital economy facilitates the integration of rural industries. Its high permeability and versatility enable seamless integration with rural sectors, promoting the rapid amalgamation of resources and data flow (Zhang et al., 2023a,2023b,2023c). This integration helps expand rural industries into emerging fields like digital agriculture, e-commerce, and tourism, while coordinating supply chains, production, processing, and sales.

Lastly, the digital economy significantly improves the efficiency of rural industries. It serves as a powerful innovation driver for total factor productivity (Pan et al., 2022). Technologies like the Internet and big data dismantle "information islands" caused by geographical barriers, enhancing equipment integration and information system interconnection. This leads to shared rural production resources and data, intelligent production management, increased transaction efficiency, and reduced transaction costs (Li et al., 2022). In conclusion, the digital economy is not just an auxiliary tool but a fundamental driver of transformation in rural industries. Its potential to intensify, specialize, green, integrate, and enhance the efficiency of these industries is unparalleled, making it a cornerstone for the sustainable development and revitalization of rural areas. Based on this, Hypothesis 1 is proposed:

Hypothesis 1. : The digital economy has a positive impact on rural industrial revitalization.

Furthermore, although existing literature has mentioned the role of scientific and technological innovation in promoting industries, few studies have conducted in-depth analysis of it as a mediating factor of the digital economy in rural revitalization. The digital economy is significantly shaped by technological innovation, which, in turn, profoundly impacts the development of rural industries. Technological innovation accelerates the application of knowledge in production, reducing labor and capital expenditure in technology search and information sharing. The digital economy facilitates the flow of innovative knowledge through various channels, integrating innovative technology into all aspects of rural industrial development and thereby promoting rural industrial revitalization (Pan et al., 2022). As technological advancements continue, particularly in areas like big data analytics, artificial intelligence, and the Internet of Things (IoT), the relationship between the digital economy and rural industries will evolve significantly. Enhanced data processing capabilities and more precise decision-making tools will allow rural industries to adopt smarter, more efficient production methods. This will not only improve operational efficiency but also foster innovation and economic diversification in rural areas.

As a technology-intensive economic form, the digital economy relies on digital information and digital technology as key production factors. Its widespread adoption encourages rural industries to continuously incorporate new technologies, enhancing operational efficiency and fostering innovation. Technological innovation transforms agricultural production by improving the function, form, and quality of agricultural products, altering the value creation process, and creating a conducive environment for rural industry development (Zhang et al., 2023a,2023b,2023c). This transformation not only reflected in the upgrading of the products themselves, but also affects the entire agricultural supply chain through digital empowerment, from production, processing to market distribution, forming a more intelligent and efficient supply chain system. With the continuous advancement of technological innovation, the innovation ability and competitiveness of rural industries have been comprehensively improved, which will help form a virtuous cycle of innovation ecosystem and promote the sustainable development of rural industries.

Additionally, technological innovation reshapes consumer demand and the rural industrial structure by enhancing functional experiences. With the continuous advancement of science and technology, consumer demand has shifted from traditional product quality and price driven to more personalized and experiential products. This shift in consumer demand has directly promoted the transformation of agricultural production from scale to diversification and refinement. In addition, the application of Internet information technology, payment technology, and warehousing and logistics technology has not only improved the operating efficiency of the rural industrial chain, but also promoted the deep integration of agriculture with other modern industries, forming a diversified industrial model of "Agriculture+ ". The development of e-commerce has made it easier for agricultural products to enter the vast market, and the advancement of modern logistics technology has improved the matching of supply and demand and the speed of product circulation. The advancement of financial technology has greatly improved the availability of rural financial loans and further promoted the implementation of innovative agricultural projects (Rijswijk et al., 2021). This profound integration promotes the holistic development of rural industries.

In conclusion, the digital economy creates a favorable environment for scientific and technological innovation. This innovation positively impacts the revitalization of rural industries by reconfiguring and efficiently utilizing production factors, driving sustainable development and growth in rural areas. Based on this, Hypothesis 2 is proposed:

Hypothesis 2. The digital economy has a positive impact on rural industrial revitalization by enhancing scientific and technological innovation capabilities.

2.2. Nonlinear spillover effects of the digital economy on rural industrial revitalization

There is limited discussion on the nonlinear effects of the digital economy on rural industrial revitalization. Although some studies have explored how the digital economy promotes industrial development, few literatures have explored in depth how this impact changes at different stages of development and how it is affected by technological innovation capabilities. The role of digital economic development in promoting rural industrial revitalization may be nonlinear, influenced by technological innovation capabilities, which exhibit threshold characteristics. China, with its vast territory and numerous cities at varying development levels, presents diverse economic conditions, governance standards, market environments, and digital infrastructure. These regional differences affect market participants' behaviors and decisions, leading to varying impacts of technological innovation on the digital economy's role in rural industrial revitalization (Peng and Dan, 2023).

In the early phases of digital economic development, digital networks are relatively small, scientific and technological innovation capabilities are still developing, and promoting rural industries incurs higher costs. Consequently, the digital economy's impact on rural industrial revitalization may initially be slow. However, as scientific and technological innovation intensifies and technology becomes more widespread, the digital economy's scale expands. With the increasing number of Internet users, the Internet's value is fully leveraged, amplifying the effects of scientific and technological innovation at a certain stage. This leads to exponential growth, where marginal costs between sectors decrease while marginal benefits increase. Based on this, Hypothesis 3 is proposed:

Hypothesis 3. : The impact of the digital economy on rural industrial revitalization will increase with the improvement of scientific and technological innovation capabilities.

2.3. Spatial spillover effects of the digital economy on rural industrial revitalization

The introduction of spatial economics can better analyze how the digital economy crosses geographical boundaries and thus affects the development of rural industries in neighboring areas, which helps to make up for the lack of discussion on the spatial spillover effects of the digital economy in existing research. Serdar Yilmaz et al. (2002) used panel data from 48 U.S. states from 1970 to 1997 to examine the spatial spillover effects of state-level telecommunications infrastructure investment on state output. They found that knowledge spillovers are more significant when states are geographically proximate and share similar industries or possess comparable levels of absorptive capacity. Similarly, Sun et al. (2021) analyzed data from 24 innovative countries from 1994 to 2013 to study the impact of technological innovation in specific countries on the energy efficiency performance of neighboring countries, considering geographical proximity.

As digital technology coverage expands, the digital economy can enhance cyberspace functions, broaden the spatial scope of innovative resource allocation, and strengthen inter-regional industrial relevance through network effects. The digital economy's ability to transcend traditional economic boundaries of time and space can reduce temporal and spatial distances, increase the breadth and depth of inter-regional economic activities, and promote the management and interaction of rural industries, leading to the formation of interconnected industrial chains.

Moreover, the digital economy's development attracts and cultivates digital technology talent within regions. The mobility of human capital creates a new pathway for the geographical spillover of knowledge elements, enhancing exchanges and connections between the development of rural sectors in various locations (Jiang et al., 2022). This dynamic fosters a more integrated and innovative rural economy, leveraging digital advancements to drive regional growth and collaboration. Based on this, Hypothesis 4 is proposed:

Hypothesis 4. The digital economy affects the development of rural industries in surrounding areas through spatial spillovers.

3. Research design and variable description

3.1. Model construction

To test research Hypothesis 1, this paper first construct a model to examine the direct impact of the level of digital economic development on rural industrial revitalization.

$$RIR_{it} = \alpha_0 + \alpha_1 DED_{it} + \alpha_2 control_{it} + \lambda_i + \gamma_t + \varepsilon_{it} \quad (1)$$

In formula (1), *RIR* indicates the level of rural industrial revitalization; *DED* represents the extent of digital economic development; *Control* represents the set of control variables; λ_i and γ_t represent regional and time fixed effects respectively, ε_{it} is the random error term; *i* represents the province; *t* represents the year.

To examine the possible mechanism of the digital economy's impact on rural industrial revitalization through technological innovation capabilities, this paper tests whether technological innovation capabilities are the mediating variable between the two based on the research hypothesis. Drawing on the ideas of Wen et al. (2004) on the analysis of the mechanism of action, this paper constructs the regression Eq. (3) of the digital economy development level (*DED*) on the mediating variable technological innovation capabilities (*YZ*) and the regression Eq. (4) of the digital economy developmnt level (*DED*) and technological innovation capabilities (*YZ*) on rural industrial revitlization (*RIR*), where YZ_{it} represents the mediating variable and the constructed model is as follows:

$$RIR_{it} = \alpha_0 + \alpha_1 DED_{it} + \alpha_2 control_{it} + \lambda_i + \gamma_t + \varepsilon_{it} \quad (2)$$

$$YZ_{it} = \beta_0 + \beta_1 DED_{it} + \beta_2 control_{it} + \lambda_i + \gamma_t + \varepsilon_{it} \tag{3}$$

$$RIR_{it} = \gamma_0 + \gamma_1 DED_{it} + \gamma_2 YZ_{it} + \gamma_3 control_{it} + \lambda_i + \gamma_t + \varepsilon_{it} \tag{4}$$

Taking into account "Metcalfe's Law", that is, the positive correlation between the value of the internet and the number of users, the digital economy driving the revitalization of rural industries may have a nonlinear dynamic impact, and the following panel threshold model is set:

$$RIR_{it} = \phi_0 + \phi_1 DED_{it} \times I(Adj_{it} \le \theta) + \phi_2 DED_{it} \times I(Adj_{it} > \theta) + \phi_c control_{it} + \lambda_i + \gamma_t + \varepsilon_{it} \tag{5}$$

Adj_{it} in formula (5) is the threshold variable, $I(\bullet)$ which represents an indicator function with a value of 0 or 1. When the conditions in the brackets are met, the value is 1, otherwise it is 0. Formula (5) represents a single threshold model, which can be expanded to a multi-threshold model based on corresponding econometric tests.

Finally, to investigate the spatial spillover effect of the digital economy on rural industrial revitalization, the spatial interaction terms of digital economy, rural industrial revitalization, and other control variables are incorporated into formula (1), resulting in the construction of a spatial panel econometric model:

$$RIR_{it} = \alpha_0 + \rho WRIR_{it} + \varphi_1 WDED_{it} + \alpha_1 DED_{it} + \varphi_c Wcontrol_{it} + \alpha_c control_{it} + \lambda_i + \gamma_t + \varepsilon_{it} \tag{6}$$

Among them, ρ represents the spatial autoregression coefficient, W represents the spatial weight matrix, α_1 represents the direct impact of the digital economy on rural industrial revitalization, φ_1 and φ_c is the elasticity coefficient of the core explanatory variable and the spatial interaction term of the control variable. The spatial weight matrix can measure the degree of association between spatial variables. This paper constructs the following spatial matrix to carry out empirical analysis. The specific expression is shown in Table 1:

3.2. Variable measurement and selection

3.2.1. Explained variables

The explained variable is the level of rural industrial revitalization (RIR). According to the "Guiding Opinions on Promoting the Revitalization of Rural Industries" issued by China in 2019, rural industries are defined as: rooted in counties, relying on agricultural and rural resources, with farmers as the main body, and taking the integrated development of rural primary, secondary, and tertiary industries as the path, with distinct regional characteristics, active innovation and entrepreneurship, rich business types, and close interest ties. They are industries that benefit agriculture, rural communities, and farmers. Creatively strengthening the synergy between agriculture and industry is an important strategy for rural industrial development. Therefore, rural industrial development cannot be limited to agricultural development, but should focus on modern agricultural development that integrates the primary, secondary and tertiary industries, has diversified functions and wins with quality(Yang et al., 2023). This study creates an index system based on five dimensions: intensification, specialization, greening, integration, and efficiency, then uses the entropy approach to define weights and produce the development index of rural industrial revitalization. The specific evaluation index system is shown in Table 2. By accumulating and averaging the rural industrial revitalization index for each year, this paper obtains the regional difference distribution map of the rural industrial revitalization index (2011–2021), as shown in Fig. 1.

3.2.2. Explanatory variables

The explanatory variable is the level of digital economic development(DED). Scholar Tapscott (1996) first proposed the term digital economy. The digital economy combines various views, including technological application, value production, and economic form. It is a modern economic form that uses information, knowledge, and intellectual capital as elements and uses digital technology to penetrate into the fields of manufacturing, management, and circulation(Tan et al., 2024; Peng and Tao, 2022). As a result of the Internet technology revolution, the digital economy has created new potential for commercial and social activity in a variety of fields, including information flow, knowledge transfer, e-commerce, health care, and education(Castellacci and Tveito, 2018), it eliminates the limits of traditional production variables on economic growth and allows for all-around innovation, R&D, and resource allocation. This study measures and the level of digital economic development from the perspectives of digital environment, digital industrialization, and industrial digitization. The specific evaluation index system is shown in Table 3. By accumulating and averaging the digital

Table 1
Spatial weight matrix.

Matrix	Formula	Explain
Economic Weight Matrix (W1)	$W_{ij} = \begin{cases} \frac{1}{\lvert GDP_i - GDP_j \rvert} (i \neq j) \\ 0 \quad (\quad i = \quad j) \end{cases}$	GDP is the economic development level of each province.
Economic Geography Weight Matrix (W2)	$W_{ij} = \begin{cases} \frac{1}{d_{ij}^2} \frac{1}{\lvert GDP_i - GDP_j \rvert} (i \neq j) \\ 0 \quad (\quad i = \quad j) \end{cases}$	$\frac{1}{d_{ij}^2}$is a geographic distance matrix, whose weight element is the longitude and latitude distance between the capital cities of two provinces.

Table 2
The level of development of the rural industrial revitalization.

Primary Indicator	Secondary Indicator	Indicator Description	Data Sources
Industrial Intensification	Yield per unit area of grain crops	-	National Bureau of statistics of the People's Republic of China(The following are abbreviated as NBSPRC)
	Development level of total power of agricultural machinery(watts)	Ratio of total agricultural machinery power to total sown area of crops	NBSPRC
	Machine sowing area	Natural logarithm of the area sown by machine	China Rural Statistical Yearbook
Industrial Specialization	The level of rural logistics construction	Natural logarithm of rural delivery routes	NBSPRC
	Rural professional cooperatives	Natural logarithm of farmers' cooperatives	China Rural Business Management Statistical Yearbook, China Rural Cooperative Economy Statistical Yearbook
	Number of professional Taobao villages	-	Official website of the Alibaba Research Institute
Industrial Greening	Pesticide usage per unit of output value	Pesticide usage / total agricultural output value	NBSPRC
	Water-saving irrigation area	Natural logarithm of water-saving irrigation area	China Rural Statistical Yearbook
Industrial Integration	Value added of agriculture, forestry, animal husbandry and fishery services	Value added of agriculture, forestry, animal husbandry and fishery minus value added of primary industry	NBSPRC
	Proportion of leisure agriculture demonstration counties	Ratio of leisure agriculture demonstration counties to the total number of counties in the region	Official website of the Ministry of Agriculture, Rural Affairs of the People's Republic of China
Industrial Efficiency	Land productivity	Ratio of total agricultural output value to total sown area of crops	NBSPRC
	Labor productivity	Ratio of total output value of agriculture, forestry, animal husbandry and fishery to number of employees in the primary industry	NBSPRC, China Population and Employment Statistical Yearbook

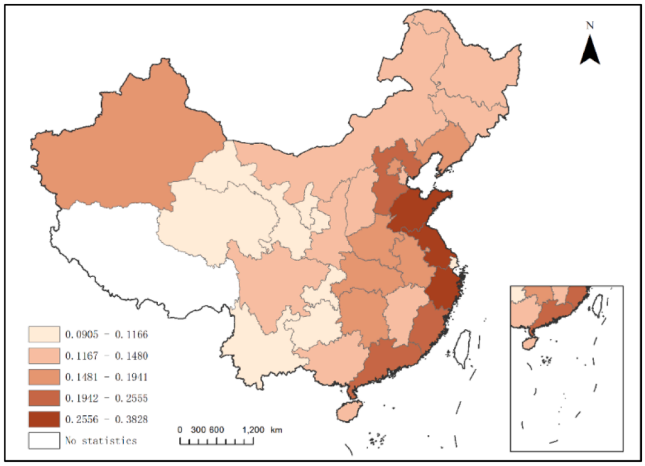

Fig. 1. Regional distribution of rural industrial revitalization index.

economy development index for each year, this paper obtains the regional difference distribution map of the digital economy index (2011–2021), as shown in Fig. 2.

3.2.3. Mediating variable

The mediating variable is scientific and technological innovation capability(YZ). This study determines the number of R&D staff and patent authorizations to assess scientific and technological innovation capabilities. The description of variables is shown in Table 4. And the entropy method is used to determine the weight of each indicator and comprehensively calculate the scientific and technological innovation capability index.

3.2.4. Control variables

In order to more comprehensively analyze the impact of the digital economy on rural industrial revitalization, this paper controls other variables that may affect rural industrial revitalization. The following control variables are mainly selected: the development level of the tertiary industry(Third), energy consumption(Energy), freight transport capacity(Traffic), urbanization level(Town), the level of opening up(Open). The description of the control variables is shown in Table 5.

3.2.5. Dataset description

Because of the vast amount of missing data in Tibet, Hong Kong, Macao, and Taiwan, this article uses data from 30 provinces from 2011 to 2021 as the research object, excluding Tibet, Hong Kong, Macao, and Taiwan. The data is primarily derived from the National Bureau of statistics of the People's Republic of China, China Rural Statistical Yearbook and China Statistical Yearbook et al. from 2011 to 2021. This article employed linear interpolation to fill in the missing data from particular years.

4. Empirical test and result analysis

4.1. Benchmark regression analysis

Before testing model (1), this paper uses F test and Hausman test to determine the best model. The F test demonstrates that the fixed effect model is superior than the mixed model because the P value is 0.0000. From Hausman test results, the P value is 0.0000, hence the random effect model's basic assumptions are not met and the fixed effect model is preferable. The test results are shown in Table 6.

Table 7 reports the benchmark regression results of the digital economy-driven rural industry revitalization. In columns (1) and (2), the estimated coefficient of the development level of the digital economy(DED) is significantly positive, the level of development of the digital economy increased by 1, and the revitalization of rural industries increased by 62.01 %, proving that the development of the digital economy has a significant positive impact on the revitalization of regional rural industries. After controlling for five variables, the influence of digital economic development on rural industrial revitalization remains significant at the 1 % level and support research Hypothesis 1.

4.2. Analysis of mechanism of action

In order to verify Hypothesis 2, this paper uses scientific and technological innovation capability (YZ) as the mediating variable and conducts regression analysis through the mediation effect test model. The regression results are shown in Table 8. Column (1) proves that the development of the digital economy has a significant positive impact on the revitalization of regional rural industries. Column (2) verifies whether the digital economy can promote the improvement of scientific and technological innovation capabilities. Among

Table 3
The level of development of the digital economy.

Primary Indicator	Secondary Indicator	Indicator Description	Data Sources
Digital Environment	Internet penetration rate	The proportion of Internet users to the permanent population	China Statistical Yearbook
	Internet broadband infrastructure	Internet broadband access port density	China Statistical Yearbook
	Mobile phone penetration rate	Number of mobile phone users per 100 people	China Statistical Yearbook
	Information transmission breadth	Optical cable line density	China Statistical Yearbook
Digital Industrialization	Internet related professionals	Number of employees in information transmission, software and information technology services	China Statistical Yearbook, China Statistical Yearbook of The Tertiary Industry
	Internet-related output	Total telecommunications business volume per capita	China Statistical Yearbook
	Software business revenue	Natural logarithm of software business revenue	NBSPRC
Industrial Digitalization	Proportion of enterprises with e-commerce transaction activities	-	China Statistical Yearbook
	Number of websites owned by the enterprise	-	China Statistical Yearbook
	E-commerce transaction volume	-	China Statistical Yearbook

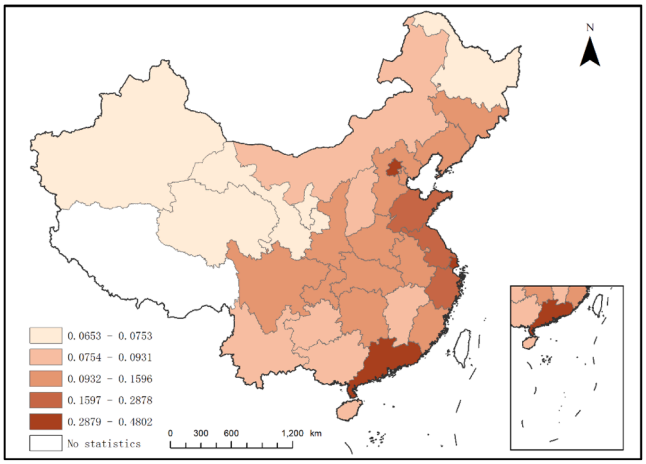

Fig. 2. Regional distribution of digital economy index.

Table 4
Description of and mediating variables.

Variables	Description	Data Sources
YZ	The number of R&D staff Patent authorizations	China Statistical Yearbook on Science and Technology NBSPRC

Table 5
Description of and control variables.

Variables	Description	Data Sources
Third	The ratio of the added value of the tertiary industry to the regional GDP	NBSPRC
Energy	The proportion of electricity consumption	NBSPRC
Traffic	The natural logarithm of the total freight volume	NBSPRC
Town	The proportion of urban population	NBSPRC
Open	The proportion of total imports and exports in GDP	NBSPRC

Table 6
Test results for regression model selection.

Test Method	Test results
F-test	11.77***
Hausman-test	103.39***

them, the development level of the digital economy and the scientific and technological innovation capabilities There is a positive correlation and it is significant at the 1 % level. The regression coefficient of the digital economy in column (3) is 0.4300, which is smaller than the estimated value of the baseline regression of 0.6201. Compared with column (1), the impact coefficient of the digital economy on rural industry revitalization in column (3) has declined, indicating that technological innovation The improvement of capabilities is the mechanism through which the digital economy drives the revitalization of rural industries. That is, the digital economy promotes the revitalization of rural industries by improving technological innovation capabilities. The empirical results confirm the existence of the mechanism and support research Hypothesis 2.

4.3. Robustness tests

4.3.1. Delete municipalities

In view of the differences in policy support, comprehensive economic strength, and other aspects between China's municipalities, this article deletes the sample data of the four municipalities of Beijing, Tianjin, Shanghai, and Chongqing from the original sample, and analyzes the sample data of the remaining 26 provinces. The regression results are shown in Table 9. In column (2), the regression coefficient of digital economy is 1.2949 and is significant at the 1 % level. It can be seen that the digital economy has a significant positive impact on driving the revitalization of rural industries after deleting the municipality samples, it may be demonstrated that the

Table 7
Benchmark regression results of the digital economy driving rural industrial revitalization.

Variable	RIR	
	(1)	(2)
DED	0.4754***	0.6201***
	(5.8453)	(5.0050)
Third		0.2047
		(1.4851)
Energy		0.8096
		(0.8400)
Traffic		0.0658**
		(2.9471)
Town		0.5268*
		(2.3536)
Open		−0.0097
		(−0.1878)
cons	−0.0332	−1.3090***
	(−1.0866)	(−4.6851)
N	330	330
R^2	0.7704	0.7833
Regional effect	YES	YES
Time effect	YES	YES

Note: (1) ***, **, and * represent significant at the 1 %, 5 %, and 10 % confidence levels respectively; (2) The t value is in parentheses, the same below.

Table 8
Test results of the mechanism of the digital economy driving rural industry revitalization.

Variable	RIR (1)	YZ (2)	RIR (3)
DED	0.6201***	0.3562***	0.4300**
	(5.0050)	(7.4723)	(3.2363)
YZ			0.5336***
			(3.5291)
Third	0.2047	−0.0327	0.2222
	(1.4851)	(−0.6173)	(1.6429)
Energy	0.8096	0.1457	0.7319
	(0.8400)	(0.3928)	(0.7743)
Traffic	0.0658**	0.0246**	0.0527*
	(2.9471)	(2.8653)	(2.3719)
Town	0.5268*	0.9057***	0.0436
	(2.3536)	(10.5153)	(0.1684)
Open	−0.0097	−0.0108	−0.0039
	(−0.1878)	(−0.5434)	(−0.0777)
cons	−1.3090***	−0.3321**	−1.1318***
	(−4.6851)	(−3.0893)	(−4.0640)
N	330	330	330
R^2	0.7833	0.9935	0.7917
Regional Effect	YES	YES	YES
Time Effect	YES	YES	YES

regression results are not influenced by specific samples and the conclusions of the model are robust. Municipalities may have an impact on the overall results due to their unique economic development levels and policy environments. By excluding these samples, this paper verifies that the conclusions do not rely on these special areas, but apply to a wider range of areas, the research Hypothesis 1 still hold.

4.3.2. Variable substitution

In order to further verify the positive impact of the digital economy on the revitalization of rural industries, this study replaces the explained variables and explanatory variables, replacing pesticide usage per unit of output value with plastic film usage per unit of output value, and replacing optical cable line density with mobile phone base station density, the regression results are shown in Table 9. In columns (4), after replacing the explained variables, the regression coefficient of digital economy is 0.6204, which is significant at the 1 % level. In columns (6), after replacing the explanatory variables, the regression coefficient of digital economy is 0.4151, which is significant at the 1 % level. Indicating that the research results are highly robust. It means that the research conclusions do not rely on specific variable settings and have high credibility and application value.

Table 9
Robust test results.

Variable	Delete municipalities		Replace the explained variable		Replace the explanatory variable	
	(1)	(2)	(3)	(4)	(5)	(6)
DED	1.4115***	1.2949***	0.4757***	0.6204***	0.3515***	0.4151***
	(13.1003)	(9.9982)	(5.8607)	(5.0153)	(4.6821)	(3.3994)
Third		0.2062		0.1971		0.2260
		(1.6813)		(1.4321)		(1.6045)
Energy		−0.2444		0.7973		0.7705
		(−0.2974)		(0.8285)		(0.7799)
Traffic		0.0982***		0.0656**		0.0733**
		(4.8297)		(2.9409)		(3.1962)
Town		−0.7744**		0.5219*		0.4708*
		(−3.1356)		(2.3353)		(2.0050)
Open		0.0201		−0.0087		−0.0484
		(0.3067)		(−0.1687)		(−0.9031)
cons	0.1212***	−0.7717**	−0.0341	−1.2987***	0.0032	−1.2493***
	(8.3751)	(−2.9388)	(−1.1190)	(−4.6557)	(0.1087)	(−4.3205)
N	286	286	330	330	330	330
R^2	0.8451	0.8597	0.7718	0.7845	0.7613	0.7735
Regional Effect	Yes	Yes	Yes	Yes	Yes	Yes
Time Effect	Yes	Yes	Yes	Yes	Yes	Yes

4.3.3. Endogeneity test

In order to alleviate the endogeneity problem, this paper uses one lag period of the digital economy as an instrumental variable and uses the instrumental variable two-stage least squares method to test possile endogeneity problems. The development of the digital economy has a certain degree of continuity. The level of the digital economy in the previous period will affect the current digital economy performance. Therefore, the digital economy with a lag of one period is closely related to the current digital economy and meets the correlation requirement. At the same time, the digital economy with a lag of one period is not affected by the current rural industrial development and the development of the digital economy in the past has no direct effect on the current rural industrial revitalization, which meets the exogenous requirement. The regression results are shown in Table 10. The Kleibergen-Paap rk LM statistic is significant at the 1 % confidence level, indicating that there is no non-identifiable instrumental variable problem. The value of the Kleibergen-Paap rk Wald F statistic is much more than 10, indicating that there is no weak instrumental variable problem and that there is a high link between instrumental variables and endogenous explanatory variables. After accounting for the endogeneity problem, the conclusion that the digital economy fosters the revitalization of rural industries remains valid.

4.4. Heterogeneity test

4.4.1. Heterogeneity analysis based on regional geographical location

Since different regions in China have great differences in geography, culture, economic development, resource conditions, etc., there is obvious regional heterogeneity in the development level of the digital economy and rural industry revitalization. Therefore, there may also be regional differences in the role of the digital economy in driving rural industrial revitalization. In order to test this hypothesis, this paper divides 30 provinces into eastern, central and western regions for regression. The regression results are shown in

Table 10
Endogeneity regression results.

Variable	First stage DED	Second stage RIR
L.DED	0.8703***	
	(17.873)	
DED		0.7832**
		(3.1163)
Control variables	Yes	Yes
Kleibergen-Paperk LM statistic		52.175
(P-value)		(0.0000)
Kleibergen-Paaprk Wald F statistic		318.372
10 %maximal IV size		16.38
15 %maximal IV size		8.96
20 %maximal IV size		6.66
25 %maximal IV size		5.53
R^2	0.9775	0.5983
N	330	330
Regional Effect	Yes	Yes
Time Effect	Yes	Yes

Table 11
Heterogeneity test results.

Variable	RIR East	RIR Central	RIR West	RIR Rural Individual Employment Is Large in Scale	RIR Rural Individual Employment Is Small in Scale
DED	0.5270*	0.8166***	0.4707***	1.4716***	−0.0830
	(2.6278)	(5.4884)	(7.0050)	(4.4431)	(−1.3569)
Third	−0.2014	0.1654*	−0.0164	−1.5375**	0.0020
	(−0.4668)	(2.2796)	(−0.5051)	(−3.0031)	(0.0338)
Energy	4.5504*	−2.1531**	0.7873**	0.6109	0.4573
	(2.5245)	(−3.0301)	(3.1343)	(0.3665)	(0.8586)
Traffic	0.1285**	−0.0085	0.0228***	0.1355**	0.0226*
	(3.0396)	(−0.6795)	(3.9189)	(2.8239)	(2.1849)
Town	2.3265***	0.3775	0.2684**	−0.8969	0.0819
	(5.9440)	(1.8523)	(3.1507)	(−1.7269)	(0.7670)
Open	−0.0424	−0.1197	0.0226	0.4317*	−0.0826***
	(−0.4619)	(−1.3833)	(1.0495)	(2.6125)	(−3.8466)
cons	−3.1342***	−0.0043	−0.3761***	−0.6307	−0.0450
	(−5.4740)	(−0.0287)	(−4.5198)	(−0.9455)	(−0.3462)
N	121	88	121	110	220
R^2	0.8476	0.9258	0.9705	0.8524	0.8711
Regional Effect	Yes	Yes	Yes	Yes	Yes
Time Effect	Yes	Yes	Yes	Yes	Yes

Table 11. The results show that the effect size of digital economy driving the revitalization of rural industries is "Central > Western > Eastern". The possible reason is that the central region has made significant progress in the construction of digital economic infrastructure. With the broad use of technologies including as 5 G, big data, and cloud computing, rural industries in the central region may now efficiently access digital networks and benefit from the ease that digital technologies provide. Simultaneously, rural industries in the central region have a robust inclination and capacity to undergo digital transformation, enabling them to more effectively align with the developmental requirements of the digital economy era. For the western region, the region is rich in natural resources and has the potential to develop characteristic industries. Through the empowerment of digital technology, these resource advantages can be transformed into industrial advantages and promote the rapid development of rural industries. Moreover, the western region regional policy support and capital investment also provide a strong guarantee for the digital economy to drive the revitalization of rural industries. In contrast, the digital economy's revitalizing effect on rural industries in the eastern region is slightly less pronounced. This could be because the eastern region's rural industries are developing faster than those in the middle and western areas. Compared with the central and western regions, the digital transformation in the eastern region is relatively mature and the growth potential has been released to a certain extent. At the same time, the eastern region is also facing more intense market competition and resource constraints, which may limit the further role of the digital economy in the revitalization of rural industries.

4.4.2. Heterogeneity analysis based on the scale of rural individual employment

The employment choices of rural residents are inseparable from the revitalization of rural industries. The growth of rural non-agricultural employment, mainly rural individual employment, is conducive to ensuring the supply of human resources for rural industries and promoting the optimization of rural industrial structures. Rural individual employment refers to employment in rural areas, with individuals or families as business units, and those who have obtained a "Business License" or have not obtained a license but are actually engaged in industrial and commercial operations. Regions with different scales of rural individual employment have different effects on the revitalization of rural industries driven by the digital economy. Based on the different scales of rural self-employment, this article divides the sample into areas with large rural individual employment and small rural individual employment, and performs regression on them. The results are shown in Table 11. The results show that in areas with large rural individual employment, the development level of the digital economy has significantly driven the revitalization of rural industries; in areas with small rural individual employment, the development level of the digital economy has not yet been able to drive the revitalization of rural industries. The possible reason is that in areas where rural individual employment is large, villages tend to have more complete digital infrastructure, such as high-speed broadband network coverage and smart logistics systems. Rural residents can use the internet platform for non-agricultural employment, which involves and digitalization-related industries, such as rural e-commerce, digital cultural tourism and other digital service industries, thus promote the ability of rural industries to access and apply digital technologies, making the digital economy's role in promoting the revitalization of rural industries more obvious. In areas with small rural individual employment, the rural industrial structure may be relatively simple and traditional, such as agriculture and traditional handicrafts, lacking diversity and innovation, these industries are less affected by the digital economy, limiting the scope of application of digital technology in these areas. and depth, making it difficult to highlight the effect of the digital economy on the revitalization of rural industries.

5. Further analysis

5.1. Nonlinear spillover effects

In order to verify that the development of the digital economy promotes the revitalization of rural industries and has non-linear spillover effects, this paper uses scientific and technological innovation capabilities(YZ) as a threshold variable and uses a panel threshold model to conduct regression analysis. Based on the method of Hansen (1999), after repeated sampling 500 times using the bootstrap method, it was found that scientific and technological innovation ability significantly passed the double-threshold test, so a double-threshold regression model was set. The threshold regression results are shown in Table 12. The impact of the digital economy on rural industrial revitalization varies with the level of scientific and technological innovation. When the scientific and technological innovation capability is lower than 0.7968, the coefficient of the digital economy is 0.0796 and is not significant. This could be due to the risks associated with the first integration of the digital economy with rural businesses, such as extensive management delayed payback periods, and high trial and error costs. And the digital economy is not large enough, the motivation for the digital transformation of rural industries is still insufficient. When the scientific and technological innovation capability is greater than 0.7968 and less than 0.8786, the coefficient of the digital economy is 0.4936 and is significant at the 10 % level. It is clear that as the digital economy continues to develop, digital technology and traditional rural industries are integrating more quickly, promoting rural industry revitalization. When the scientific and technological innovation capability is greater than the second threshold 0.8786, the coefficient of the digital economy rises to 0.8330 and significant at the 1 % level. For example, the "Tao-bao Village" is a common kind of entrepreneurship for Chinese farmers that employs digital technology and has progressed through the embryonic, growth, and rapid expansion stages. In its infancy, only a small number of urban marginalized people were exposed to e-commerce, and the number of Taobao villages remained modest. However, with the support of the government and the promotion of digital technology, the characteristics of Taobao villages' clustered growth and fission-like diffusion have been strengthened year by year, and rural e-commerce represented by "Taobao villages" has flourished (Li et al., 2023). It is clear that when scientific and technological innovation capability exceeds the first threshold value, the digital economy can promote the revitalization of rural industries. As the threshold value of scientific and technological innovation capability increases, so does the role of digital economic development in promoting the revitalization of rural industries. Therefore, it is verified that the digital economy has a nonlinear characteristic in the revitalization of rural industries, and this dynamic effect is regulated by the scientific and technological innovation capability. Research Hypothesis 3 is supported.

5.2. Spatial spillover effect

In order to test whether there is a spatial effect in the research object, this article uses the Moran'I index method to calculate the spatial effect of the digital economy and rural industry revitalization under the economic geography weight matrix(W2). As shown in the results of Table 13, under the economic geography weight matrix, the Moran'I index of the digital economy is significant and positive, and the Moran'I index of rural industrial revitalization is mostly significant and positive, indicating that the spatial distribution of digital economic development and rural industrial revitalization has significant spatial autocorrelation, and there is a clustering phenomenon in the spatial distribution of the two.

Before conducting spatial econometric analysis, this paper conducts Lagrange Multiplier Test, Likehood Ratio Test, Wald test, and Hausman test in order to ensure the applicability of the spatial model. As shown in Table 14, the Lagrange Multiplier Test was passed in two different spatial weight matrices, which shows the rationality of choosing a spatial econometric model. At the same time, this paper passed the Likehood Ratio Test and Wald Tests, indicating that the null hypothesis was strongly rejected, and the Spatial Dubin Model could not be degenerated into Spatial Autoregressive Model or Spatial Error Model, so the Spatial Dubin Model was better. On

Table 12
Regression results of the threshold model for rural industrial revitalization driven by the digital economy.

Variable		YZ (1)
Threshold	q_1	0.7968
	q_2	0.8786
$DED \bullet I(\mathrm{Th} \leq q_1)$		0.0796
		(0.5060)
$DED \bullet I(q_1 < \mathrm{Th} < q_2)$		0.4936*
		(2.1952)
$DED \bullet I(\mathrm{Th} \geq q_2)$		0.8330***
		(3.7289)
cons		−0.9071*
		(−2.0676)
Control variables		control
Regional effect		YES
Time effect		YES
N		330
R^2		0.7996

Table 13
Moran'I index.

Variable	Digital Economy			Rural Industry Revitalization		
	I	Z	p-value	I	Z	p-value
2011	0.442	4.129	0.000	0.144	1.535	0.062
2012	0.409	3.978	0.000	0.113	1.267	0.103
2013	0.352	3.414	0.000	0.104	1.189	0.117
2014	0.329	3.284	0.001	0.106	1.198	0.115
2015	0.329	3.276	0.001	0.124	1.366	0.086
2016	0.302	3.036	0.001	0.165	1.754	0.040
2017	0.280	2.829	0.002	0.160	1.738	0.041
2018	0.273	2.758	0.003	0.160	1.778	0.038
2019	0.293	2.960	0.002	0.166	1.860	0.031
2020	0.291	2.971	0.001	0.163	1.801	0.036
2021	0.276	2.829	0.002	0.180	1.976	0.024

Table 14
Specification test results of spatial econometric model.

Content	Economic Weight Matrix(W1)	Economic Geography Weight Matrix(W2)
R-LM-lag	12.161[0.0000]	34.991[0.0000]
R-LM-error	77.904[0.0000]	76.308[0.0000]
LR-lag	12.98[0.0434]	17.50[0.0076]
LR-error	13.64[0.0339]	21.51[0.0015]
Wald-lag	17.26[0.0084]	16.79[0.0101]
Wald-error	14.77[0.0221]	14.37[0.0257]
Hausman	26.05[0.0168]	49.78[0.0000]

the basis of the Spatial Dubin Model, both matrices also passed the Hausman Test, so this paper chose the fixed effect model. In addition, this paper regressed the region fixed, time fixed, and double fixed effects respectively, and believed that the time region double fixed effect model was more appropriate according to the Log-likelihood value. In summary, based on the series test, this paper adopts the spatial and temporal two-way fixed effects model of the Spatial Durbin Model.

This paper conducts a regression test through the Spatial Durbin Model based on the economic weight matrix (W1) and the economic geography weight matrix (W2). The results are shown in Table 15. Firstly, the digital economy has a positive impact on rural industry revitalization at the 1 % level in the two different matrix weight spatial Durbin models. Taking W1 as an example, for every 1 unit increase in the digital economy index and the rural industry revitalization index increases by 0.5278 units. Secondly, the interaction term between the digital economy and the weight matrix reveals that the digital economy's spillover effect on the revitalization of rural sectors is negative and significant at the 1 % level in W1, but not in W2. It is clear that the local digital economy has a negative impact on the revitalization of rural industries in the surrounding areas. At the same time, according to the spatial autocorrelation coefficient, rural industry revitalization has a significant positive spillover effect under W1 but an insignificant negative spillover effect under W2, indicating that rural industries revitalization in different regions is spatial heterogeneity, the revitalization of rural industries in this region can both drive and inhibit the revitalization of industries in surrounding areas. The possible reason why the development of local rural industries inhibits the development of rural industries in surrounding areas is that under market-economy conditions, factor owners will optimise resource allocation in order to maximise profits, and talent, technology, capital, etc. tend to move to economically developed locations. As a result, as cross-regional resource flows increase in magnitude and resource competition across regions heats up, local industries absorb factor resources from neighbouring locations. Regions with higher rural industrial revitalization indexes can attract more factor resources, boosting the growth of regional rural industries. Regions with low rural industrial revitalization indices lack the inflow of high-quality factor resources and struggle to grow further, resulting in a "syphon effect" in rural industries between regions (Chen and Wang, 2022). Compared with developed Western countries, China's digital economy started late, and due to the different initial endowments of various villages in China, the development of digital infrastructure and technology levels varies. The higher the concentration of digital platforms and technologies, the greater the competitive advantage of the village, and the higher the concentration of surrounding high-quality production factors in the village (Wang et al., 2024a,2024b,2024c). The "siphon effect" in regional economic growth is manifested in the strong attraction of economically developed or strong regions to human and material resources in other surrounding areas, prompting these resources to further concentrate in strong regions (Xu et al., 2024). Although developed countries may have a certain siphon effect, because developed countries have a wider coverage and more complete development of digital infrastructure, with the strong connectivity and resource sharing capabilities of the digital economy, the development of rural industries in developed countries is more likely to show a positive spillover effect (Kirschning and Mrożewski, 2024), thereby promoting the coordinated development of various rural industries in the region.

This article refers to the method proposed by Partridge et al. (2012) and further performs full differential on the Spatial Durbin model. As shown in Table 15, the direct effect, indirect effect and total effect of the digital economy on the revitalization of rural

Table 15
Test results of Spatial Durbin Model.

Spatial Weight Matrix Variable	Economic Weight Matrix(W1) (1)	Economic Geography Weight Matrix(W2) (2)
DED	0.5278***	0.4843***
	(5.0205)	(4.6905)
WDED	−1.6938***	−0.2648
	(−3.9388)	(−0.8838)
rho	0.2414**	−0.0158
	(2.4194)	(−0.2096)
Control variables	Yes	Yes
Direct Effect	0.4712***	0.4872***
	(4.1354)	(4.6002)
Indirect Effect	−2.0048***	−0.2770
	(−3.1730)	(−0.9312)
Total Effect	−1.5336**	0.2102
	(−2.2442)	(0.6664)
Log-likelihood	633.7556	652.0436
r2	0.2468	0.0217
N	330	330

industries are obtained. From the perspective of direct effects, the direct effect coefficients are highly consistent with the regression coefficients of the Spatial Durbin Model. The digital economy promotes the revitalization of rural industries in the region and both are important at the 1 % level in two different weight matrices, taking W2 as an example, for every increase in the digital economy index by 1 unit, the rural industry revitalization index increases by 0.4872 units. The spillover effect is the difference between the total effect and the direct effect. The spillover effect coefficient is highly consistent with the regression coefficient of the spatial Durbin model. In W2, the digital economy shows an insignificant negative effect. In W1, the digital economy shows a significant negative effect, if the development level of the digital economy in the surrounding areas increases by 1 unit, the level of local rural industries revitalization decreases by approximately 2.0048 units. It can be seen that the spatial spillover effect of the digital economy is mainly negative. This reflects the "siphon effect", that is, capital, technology, talent and other resources tend to gather in areas with more developed economies or higher growth potential, resulting in a lack of factor resources for rural industrial development in surrounding areas. From the perspective of the total effect, the coefficients of the total effect in the two matrices are both positive and negative, indicating that the digital economy in one region can both promote and inhibit the revitalization and development of rural industries in other regions. In summary, research Hypothesis 4 is supported.

6. Conclusions

6.1. Research conclusion

The digital economy promotes innovation, improves infrastructure, promotes employment and reduces poverty. While achieving rural industrial revitalization, it also helps promote the realization of multiple UN Sustainable Development Goals and provides strong support for the sustainable development of rural areas. The application of digital technology and the development of rural industries enable villagers to enter the market and obtain resources more conveniently, increasing economic revenue and eventually eliminating poverty. Simultaneously, improving agricultural production efficiency and increasing employment possibilities help to promote the growth of sustainable agriculture and the economy, which is consistent with the United Nations Sustainable Development Goal of "End poverty in all its forms everywhere", "Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all" and "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation".

Based on the panel data of 30 provinces in China from 2011 to 2021, this paper measures the comprehensive index of rural industrial revitalization and the digital economy, and empirically analyzes the mechanism and impact of the digital economy on rural industrial revitalization. The following conclusions are drawn:

Firstly, this paper demonstrates that the digital economy directly affects and significantly drives rural industrial revitalization, and Hypothesis 1 was supported. Furthermore, this article reveals that technological innovation capability is one of the important transmission paths for the digital economy to drive the revitalization of rural industries, the digital economy has a positive impact on rural industrial revitalization by enhancing scientific and technological innovation capabilities, Hypothesis 2 were supported.

Secondly, there is heterogeneity in the digital economy driving rural industrial revitalization. From the perspective of regional geographical location, compared with the eastern region, the role of the digital economy in promoting rural industrial revitalization in the central and western regions is more significant, which may be related to differences in resource endowment and economic location. From the perspective of rural individual employment scale, in areas with large rural individual employment scale, the effect of the digital economy in promoting rural industrial revitalization is more significant, while in provinces with small rural individual employment scale, the driving effect of the digital economy on rural industries has not yet been reflected, which may be related to regional infrastructure and industrial structure foundation.

Thirdly, with the continual enhancement of scientific and technological innovation capabilities, the role of the digital economy in

boosting rural industrial revitalization has nonlinear characteristics. Because of the high technical threshold and skills shortage, the digital economy may be challenging to popularize and implement in rural areas in its early stages. However, when the amount of scientific and technological innovation exceeds a key point, it produces explosive growth and propels rural industries to a qualitative leap. Therefore, the impact of the digital economy on rural industrial revitalization will increase with the improvement of scientific and technological innovation capabilities. Hypothesis 3 was supported.

Fourthly, the digital economy has a spatial spillover effect on rural industrial revitalization. It can promote the revitalization of local and surrounding rural industries through information sharing, market expansion, etc. However, when a region's digital economy grows rapidly, it may attract resource elements from surrounding areas to concentrate there, resulting in a "syphon effect" that inhibits the revitalization and development of rural industries in neighbouring regions. Therefore, the digital economy affects the development of rural industries in surrounding areas through spatial spillovers and Hypothesis 4 was supported.

Future research can combine qualitative research methods, such as case studies or in-depth interviews, to investigate the specific mechanism of the digital economy on various types of rural industries and provide a more in-depth understanding of the complex relationship between the digital economy and industrial revitalization. In addition, a more comprehensive indicator system for the digital economy and rural industries can be constructed in the future.

6.2. Policy recommendations

Based on the above conclusions, this study proposes the following recommendations. Firstly, the government should expand investment for scientific and technological innovation to guarantee that rural areas have reliable network coverage and a strong digital infrastructure. Secondly, enterprises should actively participate in scientific and technological innovation, strengthen cooperation with research institutes, universities, and other scientific research organisations, jointly conduct technology research and development, talent training, and project cooperation, explore market-oriented paths for scientific and technological innovation, realise the transformation and application of technological achievements, and provide intellectual support. Finally, rural residents should actively participate in digital skills training to increase their digital literacy and application capabilities, allowing them to better respond to the needs of the developing digital economy. Simultaneously, with government assistance, rural residents can use digital technology to start and explore new business models and profit points.

CRediT authorship contribution statement

Lin Xiaohui: Writing – original draft, Software, Methodology. **DU Anna Min:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Conceptualization. **Peng Ting:** Writing – original draft, Software, Formal analysis, Data curation. **Wang Shucui:** Investigation, Funding acquisition, Formal analysis, Data curation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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