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Research on the Impact Mechanism and Empirical Study of the Digital Economy on Rural Revitalization in the Yangtze River Economic Belt

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Abstract: As a new engine of China's economic development, the digital economy is playing an important role in rural revitalization. Due to the impact of the novel coronavirus epidemic, there is a lack of recent empirical research on the digital economy and rural revitalization and development of the Yangtze River Economic Belt. Based on the provincial panel data of 11 provinces in the Yangtze River Economic Belt from 2014 to 2022, this paper calculates the comprehensive development level of the digital economy and rural revitalization and conducts a benchmark regression on their relationship. The results of the heterogeneity analysis show that the impact of the digital economy on rural revitalization in the upper and middle reaches of the Yangtze River is stronger than that in the lower reaches. Then we adopt the Moran index and spatial Durbin model for further regression analysis, and find that there is a spatial autocorrelation between the digital economy and rural revitalization. The digital economy of the Yangtze River Economic Belt has a spatial spillover effect on rural revitalization. To effectively harness the digital economy's role in advancing rural revitalization, it is crucial to tailor resource allocation to local conditions, implement targeted policies, and establish a robust monitoring and evaluation system. This strategy aims to facilitate the seamless integration of the digital economy with rural revitalization, thereby achieving synergistic effects and promoting comprehensive, sustainable development in both economic and social dimensions.

Keywords: digital economy; rural revitalization; theoretical mechanism; spatial spillover effect; Yangtze River Economic Belt

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1. Introduction

With the development of the global digital wave, the digital economy has become an important engine to promote the transformation and growth of the global economy. As an emerging force, the digital economy is profoundly reshaping the face and future of China's rural economy. The 14th Five-Year Plan for the Development of the Digital Economy marked the digital economy's development to a new step in China [1] and provides policy guidance for digital construction. As a key pillar of China's economic development, the Yangtze River Economic Belt is rich in history, culture, and economic significance. However, it also confronts pressing challenges and rare opportunities for rural economic transformation and development. Therefore, focusing on the Yangtze River Economic Belt, this research aims to explore how the digital economy can drive rural revitalization and development. It is crucial to uncover the spatial characteristics, direction, and intensity of the digital economy's impact on rural revitalization. Such insights are significant for advancing the high-quality development of rural revitalization efforts.

As we know, the progress of information technology has promoted the rapid development of the digital economy. Academic circles gradually began to pay attention to the

impact of the digital economy on various fields. The concept of the digital economy was first proposed by Don Tapscott [2], and is mainly applied in the fields of e-commerce and information technology infrastructure. The digital economy is fundamentally a new economic paradigm that integrates information and communication technology deeply into the development of social productive forces [3]. In terms of the micro-impact of the digital economy, Yang et al. [4] believe that the digital economy can reshape the strategic mission of enterprises, enhance production momentum, and create higher comprehensive value, thus driving the high-quality development of enterprises. Hu et al. [5] found that the digital economy can promote enterprise–industry–university–research cooperation, improve patent return rate, and promote enterprise innovation. In addition, the development of the digital economy can promote the enterprise growth rate [6–9]. In terms of the macro impact of the digital economy, Qi et al. [10] believe that the digital economy has permeability and is capable of platforming and sharing. By analyzing the mechanism of the digital economy for promoting non-agricultural employment, Tian et al. [11] confirmed that the development of the digital economy is conducive to promoting the transformation of the economic structure. In addition, Zhu et al. [12] used urban panel data to confirm the effect and internal mechanism of the digital economy to enhance the resilience of the urban economy. The results show that the digital economy can mobilize the development momentum of new economic sectors and empower the development vitality of new innovation output.

The rural revitalization strategy was clearly put forward for the first time in the report to the 19th National Congress in China, highlighting the imperative of addressing the challenges faced by agriculture, rural areas, and farmers to achieve comprehensive rural development. At present, there are abundant studies on rural revitalization. Some scholars have constructed relevant evaluation index systems from five dimensions: industrial prosperity, ecological livability, rural culture, governance effectiveness, and life affluence [13–15]. The setting of these dimensions not only considers the various requirements of rural revitalization, but also emphasizes the unique advantages and positive attributes of rural areas themselves. Rural areas are characterized by rich natural resources, deep culture and traditions, strong social cohesion, and economic diversification, which provide a solid foundation for rural revitalization. Meanwhile, some scholars have analyzed the role of different subjects in rural revitalization from the aspects of poverty alleviation [16,17], rural governance [18,19], common prosperity [20], rural tourism [21] and high-quality development [22]. The role of different subjects in rural revitalization was also analyzed. In terms of the research on the development path of rural revitalization, scholars theoretically expounded the multiple driving paths of rural revitalization, such as rural e-commerce [23], social forces [24], rural tourism [25], smart finance [26], and college education [27,28]. Some scholars have also discussed the impact of policy measures in key areas, such as urban–rural integrated development [29,30], land system reform [31–33], and agricultural modernization [34,35] on rural revitalization. In particular, the rapid development of the digital economy has breathed new life into rural revitalization. Technological advancements, such as the Internet, big data, and the Internet of Things, can significantly enhance agricultural production efficiency, facilitate the distribution of agricultural products, and improve rural living conditions.

In recent years, domestic and foreign scholars have focused on the impact of the digital economy on rural revitalization, and their research has mainly been divided into two aspects: theoretical research and empirical research. In terms of theoretical research, Monda, A. et al. [36] showed that digital technology can provide tools to meet the growing need for interaction among all stakeholders involved in rural development. Wan et al. [37] believed that the digital economy plays a key role in the specialized, integrated, informationized, intensive, and green development of rural industry. It can revitalize rural industry from the aspects of efficiency improvement, industrial reform, and structural optimization. Ma et al. [38] pointed out that the internal mechanism of rural industrial revitalization empowered by the digital economy can be clarified from the four perspectives of efficiency improvement, benefit improvement, structure optimization, and industrial innovation.

The challenges facing the development of the rural digital economy were identified, and recommendations for optimizing its development path were proposed. On the other hand, Zhong et al. [39] analyzed the key characteristics of rural revitalization enabled by the digital economy from the following five perspectives: elements, modes, structures, life, and regions. They highlighted the need to further enhance farmers' digital skills, improve digital infrastructure, strengthen market supervision, and bolster governance capacity. Recently, Wang et al. [40] found that digital technology drives, digital platform support, and digital resource optimization are the internal mechanisms of the digital economy enabling migrant workers to return home and start businesses. In combination with the new characteristics and trends of migrant workers returning home to start their own businesses, the equalization of rural digital services and resources should be further realized. Lv et al. [41] also believed that the digital economy can empower rural endogenous development through the phased roles of value-added factors, technology integration, and platform support. They emphasized its potential to drive rural industrial innovation and facilitate digital integration.

In the aspect of empirical research, the research results in recent years have been continuously enriched and improved. Chen et al. [42] used panel data from 31 provinces in China covering the period from 2011 to 2020 to demonstrate the existence of rural revitalization facilitated by the digital economy. Li et al. [43] used rural revitalization as the dependent variable and digital inclusive finance as the independent variable, with rural industry development, rural fiscal expenditure levels, rural loan levels, and the depth of agricultural insurance as control variables. The empirical analysis of the relationship between them confirmed that digital inclusive finance can help rural revitalization. Zhu [44] used provincial panel data from 2013 to 2019 to empirically analyze how the digital economy enhances industrial resilience and promotes the high-quality development of rural industries. The study employed a two-way fixed effects model, an intermediary effects model, and a threshold effects model. Zhang et al. [45] conducted an empirical study that revealed the substantial positive impact of the digital economy on the diversified development of rural industries. This impact is primarily facilitated through the promotion of production factor flows and the enhancement of infrastructure construction. In addition to China, many European countries have also implemented regional development policies [36,46,47]. These policies could have provided a frame of reference to assess the effectiveness of Chinese policies in rural revitalization through the digital economy.

In summary, the impact of the digital economy on rural revitalization is mainly reflected in promoting rural economic development, improving production efficiency, enhancing quality of life, driving industrial structure adjustment, and stimulating innovation and entrepreneurship. With the continuous advancement of digital technologies and the expansion of application scenarios, research on the impact of the digital economy on rural revitalization will become more in-depth and extensive, providing solid theoretical and empirical support for achieving comprehensive rural revitalization.

It is important to note that the inherent advantages and resources of rural areas include abundant natural resources, unique cultural heritage, strong social capital, suitable productive land, low-cost living environments, ample open spaces, traditional handicrafts, and a good ecological environment. These advantages not only provide significant development potential for rural areas but also lay the foundation for sustainable development. Fully tapping into and utilizing these resources can help rural areas effectively address the challenges they face during revitalization while preserving and enhancing their unique local characteristics. In addition, although the digital economy can influence rural revitalization and bring positive effects, in reality, the digital economy may also bring potential obstacles and negative impacts to rural areas, such as digital inequality, the risk of exacerbating existing gaps, and the possibility of dependence on digital infrastructure.

In summary, as digital technology continues to advance and its application scenarios expand, research on the impact of the digital economy on rural revitalization will become in-

creasingly in-depth and comprehensive. This will provide robust theoretical and empirical support for achieving comprehensive rural revitalization.

Currently, while there is substantial content on digital economy and rural revitalization, several gaps remain, as follows:

1. Most existing theoretical analyses focus on the definition, interpretation, policy design, and implementation paths of the digital economy and rural revitalization. However, there is a lack of empirical research examining regional and industrial differences.
2. The data used in the few available empirical studies are not sufficiently novel or comprehensive, particularly regarding the impact of the COVID-19 pandemic on rural revitalization and the digital economy.
3. Despite being a crucial area for China's economic strategy and rural revitalization, the Yangtze River Economic Belt currently lacks empirical studies on the development of the digital economy and rural revitalization within this region.

To address these gaps, this paper focuses on the Yangtze River Economic Belt and constructs a comprehensive evaluation index system for digital economy and rural revitalization. It includes both theoretical analysis and empirical discussion of their relationship. The innovations of this paper are as follows:

1. Methodological innovation: We have emphasized the use of the spatial Durbin model (SDM) to account for spatial spillover effects, addressing a gap in traditional models that often overlook spatial dependencies.
2. Expansion of the research scope: The study now clearly indicates that it encompasses eleven provinces and cities within the Yangtze River Economic Belt, allowing for a more comprehensive analysis of regional disparities.
3. Policy recommendations: Based on our findings, we have proposed differentiated development strategies and policy recommendations to better leverage the digital economy for rural revitalization across various regions.

2. Theoretical Mechanism

Guided by an empirical research framework, this study focuses on testing research hypotheses through data analysis rather than relying on specific theoretical models. This methodological choice allows us to draw conclusions based on empirical evidence, thereby providing substantive insights into the relationship between the digital economy and rural revitalization. This approach not only enhances the rigor and validity of our findings but also contributes valuable empirical evidence to the field. In addition, we recommend a book, *Spatial Econometrics: Methods and Models* by LeSage and Pace [48], which can help us better understand the model design and discussion part of this article.

2.1. The Digital Economy Affects Rural Revitalization: Direct Effects

As a new form of deep integration of information technology and economy, the digital economy has played a significant role in promoting the implementation and effect of rural revitalization strategy. Specifically, the digital economy directly affects rural revitalization through the following aspects.

The combination of the digital economy with rural construction, agricultural development, and farmers' lives promotes rural modernization. Through the extensive promotion of rural digital platform and e-commerce technology, the digital economy has greatly improved the docking efficiency and circulation efficiency of the agricultural products market, further expanded the rural industrial chain, significantly enhanced the participation and income level of farmers in the market economy, and, thus, promoted the in-depth development of economic integration [49]. Secondly, the wide application of digital technology in the fields of intelligent agriculture, telemedicine, and online education has greatly improved the rural infrastructure conditions and the quality of public services and has brought a new look to the lives of rural residents. In addition, the digital economy has stimulated the full release of innovation resources in rural areas, promoted the cultivation and agglomeration of scientific and technological talents, promoted the optimization and

upgrading of rural industrial structure and diversified development, and provided solid technical support and innovation impetus for the sustainable growth of the rural economy.

The digital economy accelerates the flow of information and improves market transparency, profoundly changing the supply and demand structure in rural areas. By improving information symmetry and market transparency, the digital economy reduces information asymmetry, optimizes production efficiency on the supply side, and promotes consumption upgrading on the demand side, comprehensively reshaping the supply and demand structure in rural areas and injecting new impetus into the development of rural industries [50]. For example, the e-commerce platform will provide a transparent trading environment, promote the supply and demand sides to understand the market conditions, and help rural consumers quickly access market information. The digital economy has an impact on both the supply side and the demand side: (i) On the supply side, the digital economy promotes the development of smart agriculture. Through technologies, such as the Internet of Things and artificial intelligence, farmers can monitor and manage crops in real time, improving agricultural production efficiency and yields. At the same time, the application of digital technology can integrate and allocate rural resources more effectively and optimize the allocation of production factors. (ii) On the demand side, the digital economy has promoted the diversification of rural consumers' needs, and rural products can reach a wide range of markets through e-commerce platforms to meet different levels of personalized needs.

Digital technology has enabled the rural agricultural economy to flourish and has narrowed the income gap between urban and rural areas. First of all, the popularization of digital technology enables rural residents to have equal access to information resources, such as education, medical care, and finance, thus improving their skills and employment opportunities and increasing sources of income [51]. At the same time, the emergence of telecommuting and flexible employment opportunities allows rural residents to participate in a variety of online work or entrepreneurial activities through the Internet, further increasing their income. In addition, the rise of e-commerce platforms gives rural producers direct access to a wider market, raising product prices and reducing intermediary fees, further increasing incomes. The government implemented targeted poverty alleviation policies through digital technology, optimized resource allocation, and effectively narrowed the gap between urban and rural areas.

To sum up, this paper proposes the following hypothesis:

Hypothesis H1. *The digital economy has effectively promoted the development of rural revitalization.*

2.2. Impact of the Digital Economy on Rural Revitalization: The Spatial Spillover Effect

The development of the digital economy can weaken the influence of spatial distance, break through regional boundaries, and promote the flow of factors between regions, so as to achieve efficient allocation of resources. First of all, the popularization and wide application of digital technology has greatly improved the level of information technology in rural areas, and has, thus, promoted the improvement and development of communication infrastructure. This process not only accelerates the exchange and sharing of information and resources between rural and urban areas, but also deepens the interaction and integration of the rural economy and society, thus expanding the space and potential of rural economic development. Secondly, the widespread popularity of digital economic platforms, such as e-commerce and online services, has significantly expanded the market reach and sales channels of rural products. Through these platforms, rural agricultural products can be more efficiently exposed to the global market, improving their sales efficiency and market competitiveness. This not only creates a wider range of trade opportunities for farmers, but also stimulates the new momentum of rural economic growth and the potential for sustainable development. In addition, the application of digital technology in key areas, such as agricultural production management, environmental protection, and resource utilization has greatly improved the production efficiency and sustainable development capacity

of rural industries. Through intelligent agricultural technology and digital management system, rural areas can use resources more effectively, reduce their environmental impact, and promote the optimization and upgrading of local industrial structure in the direction of high added value and environmental protection, while further promoting the overall development of the rural economy and social stability.

To sum up, this paper proposes the following hypothesis:

Hypothesis H2. *The digital economy has a spatial spillover effect on rural revitalization.*

3. Model Design and Variable Description

3.1. Data Sources

This paper selects the panel data of 11 provinces and cities along the Yangtze River Economic Belt during 2014–2022 for research, and the data comes from some local governments in China and some online materials etc.

3.2. Description of Variables

3.2.1. Explained Variables

Rural revitalization (Rr): With reference to the index evaluation system of rural revitalization in the Strategic Plan for Rural Revitalization, 5 dimensions of industrial prosperity, ecological livability, village style civilization, effective governance, and prosperity were selected, an evaluation system of rural revitalization with 19 secondary indicators was extracted, and the index weight was calculated using the entropy method. The specific index system is shown in Table 1.

Table 1. Indicator system of rural revitalization.

Variable Name	Dimension	Secondary Indicators	Weight	Index Attribute
Rural revitalization development level	Thriving industries	Total output value of agriculture, forestry, animal husbandry, and fishery (billion yuan)	0.060	+
		Unit grain yield per unit area (kg/hectare)	0.057	+
		Mechanization level	0.070	+
		Irrigation level	0.182	+
		Investment level	0.183	+
	Ecological livability	Fertilizer application level (tons/hectare)	0.043	+
		Elderly dependency ratio (%)	0.068	+
		Number of rural doctors and health workers (persons)	0.048	+
		Agricultural film usage	0.036	+
		Forest coverage (%)	0.025	+
	Rural civilization	Entertainment consumption ratio	0.066	+
		Number of rural households with cable TV (10,000 households)	0.023	+
		Rural TV program coverage (%)	0.139	+
		Township cultural stations	0.060	+
	Effective governance	Minimum living allowance expenditure per person receiving assistance	0.057	+
		Environmental management area = area of drainage improvement + area of soil erosion control	0.070	+
	Prosperous living	Rural electricity consumption	0.182	+
		Engel coefficient (indicator of food expenditure relative to total household spending)	0.183	−
		Per capita disposable income of rural residents	0.043	+

Notes: '+' represents positive effect and '−' represents negative effect.

3.2.2. Explanatory Variables

Digital economy (De): Based on the research achievements of relevant scholars, an index evaluation system for the development of the digital economy is constructed, and indicators are selected from the three dimensions of digital economy informatization

development, Internet development, and digital transaction development according to the characteristics of the digital economy in order to measure them; the entropy method is adopted to measure the index weight. The specific index system is shown in Table 2.

Table 2. Digital Economy Indicator System.

Variable Name	Dimension	Secondary Indicators	Weight	Index Attribute
Digital Economy Development Index	Informationization development indicators	Fiberoptic cable density	0.046	+
		Density of mobile phone base stations (%)	0.036	+
		Proportion of information technology professionals (%)	0.059	+
		Total telecommunications business volume (billion yuan)	0.066	+
		Software business revenue (ten thousand yuan)	0.041	+
	Internet development indicators	Density of internet access ports (%)	0.035	+
		Mobile phone penetration rate (units per hundred persons)	0.045	+
		Proportion of broadband internet users (%)	0.049	+
		Proportion of mobile internet users (%)	0.050	+
	Digital transaction development Indicators	Number of websites per hundred enterprises (units)	0.044	+
		Number of computers used per hundred persons (units)	0.023	+
		Proportion of e-commerce enterprises (%)	0.072	+
		E-commerce sales volume (billion yuan)	0.012	+
		Online retail sales volume (billion yuan)	0.063	+

Notes: '+' represents positive effect.

3.2.3. Control Variable

To effectively measure the impact of the digital economy on rural revitalization, it is necessary to control for other factors influencing rural development. This paper selects four control variables.

Science, technology, and innovation (STI): STI promotes rural revitalization by enhancing agricultural productivity, optimizing resource allocation, promoting market-oriented agriculture, improving infrastructure, and increasing informationization. Following the existing literature and considering data representativeness, the natural logarithm of domestic patent applications granted is chosen as the measure.

Financial support for agriculture (FSF): Increased FSF through enhanced funding, subsidies, and preferential policies improves rural infrastructure, agricultural productivity, and farmer income, thus promoting rural revitalization. Referring to relevant scholars, the proportion of regional expenditure on agriculture, forestry, and water affairs to the general public budget is used as the measure.

Urbanization level (UL): UL promotes rural revitalization by facilitating rural–urban population movement, enhancing rural infrastructure, and improving public services. The proportion of the urban population to total population within each province is used as the indicator.

Economic development level (EDL): A higher EDL increases rural income and employment opportunities, thereby promoting rural revitalization. Per capita GDP is used as the measure.

These control variables are essential to isolate the specific impact of the digital economy on rural revitalization.

3.3. Calculate the Entropy Method of the Digital Economy and Rural Revitalization

The entropy method is used to calculate the development level of the digital economy and rural revitalization in 11 provinces and cities along the Yangtze River Economic Belt. The following are the specific steps of the index calculation.

3.3.1. Non-Dimensional (Standardized) Processing of Indicators

In order to eliminate the dimensional difference between the selected indicators, Formulas (1) and (2) are used for dimensionless processing of the involved positive and negative indicators, respectively.

The dimensionless processing of positive indicators is shown as follows in Equation (1):

$$x'_{ij} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})} + 0.0001 \quad (1)$$

The dimensionless treatment of negative indicators is shown as follows in Equation (2):

$$x'_{ij} = \frac{\max(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})} + 0.0001 \quad (2)$$

where x'_{ij} represents the original value of the j_{th} indicator for province i. To prevent errors in the subsequent entropy calculation, x'_{ij} needs to be shifted by 0.0001 units.

3.3.2. Indicator Weight Calculation

Based on the data after standardized processing, this paper calculates the weight of each indicator according to the entropy value of each indicator, and the specific calculation method is shown in Formulas (3)–(6). The higher the calculated entropy, the less important the indicator, and vice versa. The weights of each index obtained by the final calculation are shown in Table 1.

The index proportion is calculated as follows:

$$\mathcal{P}_{ij} = \frac{x'_{ij}}{\sum_{i=1}^{99} x_{ij}} \quad (3)$$

The index entropy is calculated as follows:

$$e_j = -(\ln 99)^{-1} \sum_{i=1}^{99} \mathcal{P}_{ij} \ln(\mathcal{P}_{ij}) \quad (4)$$

The index difference coefficient is calculated as follows:

$$g_j = 1 - e_j \quad (5)$$

The index weight determination is calculated as follows:

$$w_j = \frac{g_j}{\sum_{j=1}^{19} g_j}; w_j = g_j / \sum_{j=20}^{33} g_j \quad (6)$$

3.3.3. Calculation of the Comprehensive Development Level

By multiplying and summing the standardized data with the weights of each indicator, a comprehensive score of the level of development of the system (i.e., rural revitalization and the digital economy) can be calculated. The calculation method is shown below.

The comprehensive evaluation value of rural revitalization is calculated as follows:

$$S_{ir} = \sum_{j=1}^{19} w_j x'_{ij} \quad (7)$$

where S_{ir} represents the comprehensive evaluation value of the digital economy development of province i, w_j indicates the weight of item j, and x'_{ij} indicates the value of item j of province i after standardized processing. We calculate these one by one according to the same method to determine the comprehensive score S_{ie} of the digital economy level of province i.

3.4. Measurement Model Setting

3.4.1. Benchmark Model

To test the role of the digital economy in promoting rural revitalization, this paper sets up the following model:

$$\mathrm{Rr_{it}} = \mathrm{a_0} + \mathrm{a_1 De_{it}} + \mathrm{a_2 Con_{it}} + \mu_\mathrm{i} + \sigma_\mathrm{t} + \varepsilon_\mathrm{it} \tag{8}$$

where Rr_{it} represents the level of rural revitalization in region i at time t; De_{it} represents the level of digital economy development in region i at time t; Con_{it} represents a set of control variables influencing region i at time t; μ_i and σ_t represent region (individual) and time fixed effects, respectively; and ε_{it} represents the random disturbance term.

3.4.2. Spatial Weight Matrix

The spatial weight matrix is the basis of spatial regression analysis. It represents spatial data based on the relationship between spatial locations and is mainly used to measure spatial correlation and to find the strength of spatial relationship. Specifically, by defining a binary symmetric spatial weight matrix $\mathcal{Z}_{ij}$, the proximity of a spatial region of n positions is represented. The specific formula is as follows:

$$\mathrm{Z_{ij}} = \begin{cases} 1, \text{When i is adjacent to j} \\ 0, \text{otherwise} \end{cases} (\mathrm{i, j} = 1, 2, 3 \ldots \mathrm{n}) \tag{9}$$

where n is the number of regions and $\mathcal{Z}_{ij}$ is the element of row i and column j of the spatial weight matrix. If I = j, then $\mathcal{Z}_{ij}$ = 0. When there is an adjacent boundary between two regions, the value is assigned as 1; otherwise, it is assigned as 0.

3.4.3. Spatial Autocorrelation

Spatial connection is a prerequisite for spatial econometric analysis. When calculating the Moran index, we need to use a spatial matrix and judge the spatial relation between regions by the I value of the Moran index. In this study, the interregional Moran index is calculated annually through the geographical distance matrix.

When the Moran index is significant, it indicates that the variables have a spatial correlation. Otherwise, the spatial correlation is not significant. The Moran index ranges from -1 to 1, with a value greater than 0 indicating a positive spatial correlation between regions and a negative spatial correlation. The larger the absolute value of Moran index is, the stronger the spatial correlation is. The Moran index is divided into two categories: global and local. The global Moran index is used to analyze the aggregation of the whole spatial sequence, while the local Moran index is used to study the spatial aggregation of the local region. The relevant formulas are as follows.

The global Moran index is calculated as follows:

$$\text{Gobal Moran's I} = \frac{\mathrm{n}\sum_{\mathrm{i}=1}^{\mathrm{n}}\sum_{\mathrm{j}=1}^{\mathrm{n}}\mathrm{Z_{ij}}\left(\mathrm{X_i} - \overline{\mathrm{X}}\right)\left(\mathrm{X_j} - \overline{\mathrm{X}}\right)}{\sum_{\mathrm{i}=1}^{\mathrm{n}}\sum_{\mathrm{j}=1}^{\mathrm{n}}\mathrm{Z_{ij}}\sum_{\mathrm{i}=1}^{\mathrm{n}}\left(\mathrm{X_i} - \overline{\mathrm{X}}\right)^2} \tag{10}$$

The local Moran index is calculated as follows:

$$\text{Local Moran's I} = \frac{\mathrm{n}\left(\mathcal{X}_i - \overline{\mathcal{X}}\right)\sum_{j=1}^{\mathrm{n}}\left(\mathcal{X}_j - \overline{\mathcal{X}}\right)}{\sum_{i=1}^{\mathrm{n}}\left(\mathcal{X}_i - \overline{\mathcal{X}}\right)^2} \tag{11}$$

3.5. Descriptive Statistics

As shown in Table 3, the 11 provinces and cities in the Yangtze River Economic Belt show significant differences in terms of their digital economy, rural revitalization, scientific and technological innovation, financial support for agriculture, urbanization level, and economic development level. First, the development of the digital economy is uneven

among provinces and cities, with some regions having made remarkable progress while most regions are still at a low level, which means that the development of the digital economy within the region needs more balanced and extensive policy support. In terms of rural revitalization, the level of provinces and cities is relatively consistent, but there are still some areas that show more outstanding progress, showing that the potential and challenges of the Yangtze River Economic Belt coexist in the process of rural revitalization. At the same time, the standard deviation of the digital economy is slightly larger than that of the rural revitalization, indicating that the differences in the development level of the digital economy in various regions are relatively more prominent, while the volatility of the rural revitalization is less in different regions. Secondly, the fluctuation of science and technology innovation among provinces and cities is much higher than other variables, indicating that there is a serious imbalance in the development level of science and technology innovation among provinces and cities in the Yangtze River Economic Belt. Thirdly, the standard deviation of fiscal support for agriculture is significantly higher than the level of urbanization, indicating that there are great differences in the intensity of financial support for agricultural development among different regions, which may affect the process and development speed of urbanization in rural areas. Finally, although the level of economic development is relatively consistent on the whole, there are still some gaps. It is necessary to promote the coordinated economic development of various provinces and cities in the region through further policy optimization and resource allocation.

Table 3. Descriptive statistical results.

Variable Name	Symbol	Sample Size	Minimum Value	Maximum Value	Standard Deviation
Digital economy	De	99	0.185	0.574	0.369
Rural revitalization	Rr	99	0.037	0.688	0.27
Science and technology innovation	Sti	99	1.746	75.358	19.751
Financial support for agriculture	Fsf	99	0.715	2.059	1.23
Urbanization level	Ul	99	0.403	0.893	0.612
Economic development level	Edl	99	2.495	18.105	7.054

4. Empirical Test

4.1. Baseline Regression

First, the F test and Hausman test are carried out on the model, and the results show that the fixed effect is better than the random effect model. As such, the fixed effects model is used. Meanwhile, the explanatory variable Rr passed the stationarity test.

After controlling time and individual fixed effects, the estimated results of the digital economy on rural revitalization are shown in Table 4. It can be found that model 1 shows the impact of the digital economy on rural revitalization without controlling variables. The results show that the regression coefficient of the digital economy is 0.271, which is significantly positive at the 1% confidence level, indicating that the development of the digital economy promotes the development of rural revitalization, thus verifying hypothesis H1.

Table 4. The benchmark return of the digital economy to rural revitalization.

Variable Name	Model 1	Model 2	Model 3	Model 4	Model 5
	Rr	Rr	Rr	Rr	Rr
De	0.271 ***	0.397 ***	0.374 ***	0.243 ***	0.195 ***
	−10.571	−11.995	−12.121	−5.7	−4.257
Sti		−0.002 ***	−0.002 ***	−0.001 ***	−0.002 ***
		(−5.197)	(−4.960)	(−4.762)	(−4.932)
Fsf			0.053 ***	0.041 ***	0.039 ***
			−4.159	−3.482	−3.391
Ul				0.412 ***	0.300 ***
				−4.118	−2.791
Edl					0.011 **
					−2.458
_cons	0.295 ***	0.295 ***	0.233 ***	0.026	0.052
	40.165	45.724	14.461	0.507	1.01
N	99	99	99	99	99
R^2	0.562	0.667	0.723	0.77	0.785
F	111.744	86.073	74.023	70.178	60.721

Note: ***, ** denote significance levels of 1%, 5%, respectively. Standard errors are reported in parentheses throughout.

The influence of each control variable on rural revitalization and development is different. Control variables were gradually included in model 2 to model 5, and financial support for agriculture, urbanization, and economic development could positively affect rural revitalization to varying degrees, indicating that the higher the government's support for agriculture, forestry, and water conservancy, the faster the flow of urban and rural resources, and the higher the level of economic development, the more prominent the level of rural revitalization. However, scientific and technological innovation has played a negative role in the development of rural revitalization. The reason is that the dividends of scientific and technological innovation in the Yangtze River Economic Belt region are mainly enjoyed by cities. The Matthew effect between urban and rural areas is magnified. This is perhaps because the applicability of science and technology in rural areas is poor, the demand is not matched, and the landing is difficult, resulting in scientific and technological innovation not only promoting rural revitalization and development, but also becoming a burden on rural development. In addition, model 5 shows that after adding all control variables, the coefficient of the digital economy significantly decreases to 0.195 and increases at the same time, indicating the role of the digital economy in rural revitalization and its complex interaction with other factors. This provides important empirical support and theoretical enlightenment for further research and the formulation of regional development policies.

4.2. Robustness Test

4.2.1. Data Tailing and Truncation Processing

In order to avoid the impact of sample outliers in the model regression process on the regression results, 1% and 99% indentation and truncation processing were applied to the data, respectively, and Equation (8) was regression-performed. The results are shown in model 6 and model 7 in Table 5. According to the test, under the above processing methods, the impact of the digital economy on rural revitalization is still significantly positive at the 1% confidence level. The results of the baseline regression are not affected by extreme values.

Table 5. Robustness test results.

Variable Name	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11
	Rr	Rr	Rr	Rr	De	Rr
De	0.195 ***	0.195 ***	0.335 ***	0.130 *		
	(4.257)	(4.207)	(7.534)	(1.804)		
LDe					0.807***	0.197 ***
					(16.758)	(2.896)
Sti	−0.002 ***	−0.002 ***		0.000		−0.003 ***
	(−4.932)	(−4.857)		(0.434)		(−4.963)
Fsf	0.039***	0.039 ***		0.035 ***		0.026 *
	(3.391)	(3.230)		(3.735)		(1.935)
Ul	0.300 ***	0.296 **		0.191		0.332 *
	(2.791)	(2.592)		(1.517)		(1.832)
Edl	0.011 **	0.011 **		0.010**		0.013 **
	(2.458)	(2.418)		(2.290)		(2.629)
_cons	0.295 ***	0.296 ***	0.281 ***	0.102	0.081 ***	0.053
	(40.165)	(39.316)	(35.764)	(1.447)	(6.100)	(0.590)
N	99	98	44	66	88	88
R^2	0.562	0.557	0.639	0.895	0.787	0.724
F	111.744	108.124	56.765	84.917	280.823	37.794

Note: ***, **, and * denote significance levels of 1%, 5%, and 10%, respectively. Standard errors are reported in parentheses throughout.

4.2.2. Shorten the Time

The rural revitalization strategy was put forward in 2017. In order to avoid the impact of the proposal of the strategy on the results of the benchmark regression model, the time span was shortened to 2014–2017 and the regression analysis was carried out as in Equation (8). The results were shown in model 8. At the same time, excluding the possible impact of the COVID-19 epidemic on the effect of rural revitalization enabled by the digital economy, model 9 shortens the time window to 2014–2019, so that the actual role of the digital economy in rural revitalization can be more accurately evaluated without interference from external factors, such as the epidemic. The results show that under the above treatment methods, the impact of the digital economy on rural revitalization is still significantly positive at the confidence level of 1%, indicating that the baseline regression results of this paper are not affected by strategies and epidemics.

4.2.3. Endogeneity Test

The baseline regression estimation of the impact of digital economy development on rural revitalization may have endogenous problems. Therefore, this paper further refers to Tian Ye et al. [52]. The lag period of the digital economy was used as the instrumental variable to conduct 2SLS regression to deal with the potential endogeneity problem. The test results were shown in model 10 and model 11 of Table 5. Among these, the *p*-values of LM statistics of Kleibergen-Paap rk are all 0.0000, which significantly rejects the null hypothesis of "insufficient identification of instrumental variables". In the test of weak recognition of instrumental variables, the Wald F statistic of Kleibergen-Paap rk is also much higher than the critical value at 10% level of the Stock–Yogo weak recognition test, which shows the rationality of the selection of instrumental variables. As can be seen from model 11, after taking the one-stage lag of the digital economy as an instrumental variable and considering the endogeneity problem, the digital economy still presents a significant positive impact on rural revitalization at the level of 1%, which further confirms the conclusion obtained by the previous regression.

4.3. Heterogeneity Test

Due to differences in regional development foundations and varying degrees of digital economy development, further research explores the regional heterogeneity in how the digital economy empowers rural revitalization. Regression analyses were conducted separately for downstream, midstream, and upstream regions, with the results reported

in Table 6. The findings indicate that the regression coefficients for the digital economy are positive and highly significant across downstream, midstream, and upstream regions. Specifically, the coefficients for upstream and midstream regions are 0.384 and 0.347, respectively, while the coefficient for the downstream region is 0.174. Compared to the downstream region, the impact of the digital economy on rural revitalization is stronger in the upstream and midstream regions.

Table 6. Heterogeneity test of the impact of the digital economy on rural revitalization.

Variable Name	Model 10	Model 11	Model 12
	Downstream	Midstream	Upstream
De	0.174 ***	0.347 ***	0.384 ***
	(0.0464)	(0.0349)	(0.0293)
_cons	0.369 ***	0.319 ***	0.206 ***
	(0.0189)	(0.00687)	(0.00689)
N	36	27	36
R^2	0.313	0.812	0.847

Note: *** denote significance levels of 1%. Standard errors are reported in parentheses throughout.

Different stages of economic and digital economy development across regions lead to varying impacts on rural revitalization. Upstream and midstream regions are still in the rapid development and transformation phases, offering greater potential for enhancement and development, thereby exerting a stronger influence of the digital economy on rural revitalization. In contrast, the downstream region is relatively developed, with the digital economy development approaching maturity, resulting in a reduced marginal effect on rural revitalization.

4.4. Spatial Spillover Effect

The development of the digital economy can mitigate the influence of spatial distances, transcend geographical boundaries, and promote the flow of factors between regions, thereby achieving efficient resource allocation. Through agglomeration effects and spillover effects, the digital economy can extend its developmental dividends to other related areas, further enhancing support for and driving rural revitalization. Therefore, it is necessary to conduct an in-depth analysis of the spatial spillover effects of the digital economy on rural revitalization.

The results of the spatial autocorrelation test between the digital economy and rural revitalization are shown in Table 7. Analysis of the global Moran's index data from 2014 to 2022 across the eleven provinces in the Yangtze River Economic Belt indicates significant temporal changes and fluctuations in the spatial autocorrelation of the digital economy. Initially, policy support and infrastructure development effectively promoted common regional development, resulting in a strong positive spatial autocorrelation. However, as the digital economy entered a deeper stage, differences among regions emerged in terms of resources, policy implementation effectiveness, and market environment. The impact of the COVID-19 pandemic exacerbated these differences, leading to a weakening or even negative spatial autocorrelation in later stages.

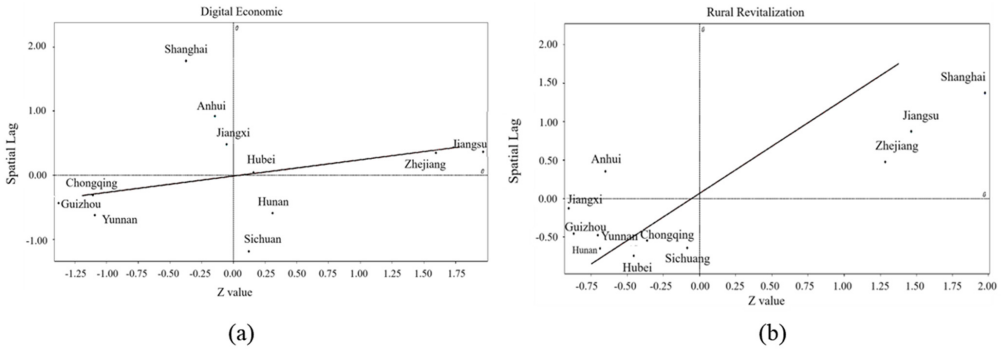
The global Moran's index for rural revitalization consistently shows highly significant positive spatial autocorrelation, indicating clear spatial clustering of rural revitalization indicators. The rural revitalization in the Yangtze River Economic Belt experienced stages including policy incubation, rapid advancement after formal proposal, adjustment during the pandemic, and recovery in the post-pandemic era. The implementation of the rural revitalization strategy significantly strengthened synergies between regions. Despite fluctuations, the overall spatial autocorrelation has remained significant throughout these periods. This validates hypothesis H2.

Table 7. Global spatial autocorrelation test of the digital economy and rural revitalization.

Year	De		Rr	
	Moran's I	z-Value	Moran's I	z-Value
2014	0.159 *	1.317	0.569 ***	3.394
2015	0.249 *	1.617	0.577 ***	3.434
2016	0.255 **	1.799	0.548 ***	3.29
2017	0.279 **	1.922	0.552 ***	3.307
2018	0.258 **	1.818	0.524 ***	3.165
2019	0.279 **	1.924	0.51 ***	3.096
2020	0.195	1.499	0.491 ***	3.002
2021	−0.03	0.354	0.535 ***	3.224
2022	−0.033	0.339	0.532 ***	3.209

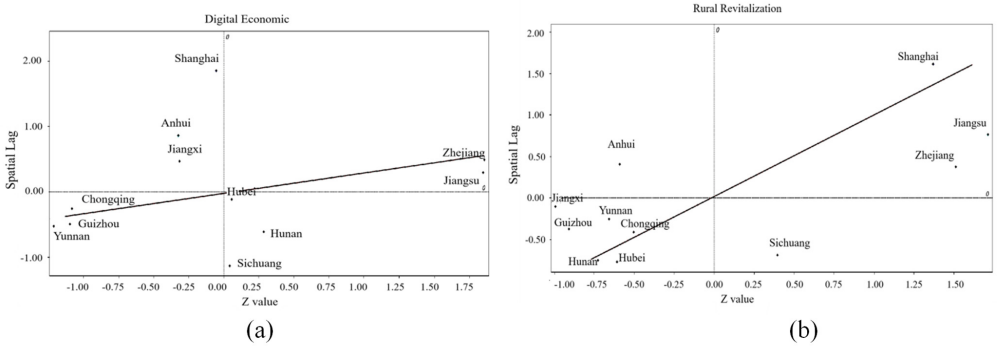
Note: ***, **, and * denote significance levels of 1%, 5%, and 10%, respectively. Standard errors are reported in parentheses throughout.

To further illustrate the degree of local regional correlation, this study selected the digital economy and rural revitalization indicators from 2014 and 2020 for local spatial analysis, as shown in Figures 1 and 2. It can be observed that "high-high" clusters of the digital economy and rural revitalization are relatively scarce and are concentrated in the downstream regions of the Yangtze River Economic Belt. "Low-low" clusters are predominantly concentrated in certain regions, such as Yunnan, Guizhou, and Chongqing, and overall spatial patterns have not significantly changed over time.



(a) (b)

Figure 1. Local spatial autocorrelation distribution of key variables in 2014. (**a**) represents the local Moreland index of the digital economy in 11 provinces and cities in 2014. (**b**) represents the local Moreland index of rural revitalization in 11 provinces and cities in 2014.



(a) (b)

Figure 2. Local spatial autocorrelation distribution of key variables in 2020: (**a**) represents the local Moreland index of the digital economy for 11 provinces and cities in 2020. (**b**) represents the local Moreland index of rural revitalization in 11 provinces and cities in 2020.

Next, diagnostic tests, such as Wald spatial lag and LR, were conducted, and this study chose the spatial Durbin model for spatial econometric regression analysis, with estimation

results shown in Table 8. The coefficient for the digital economy is significantly positive at the 5% level, and the spatial interaction term for the digital economy is also positive. This indicates that there exists a spatial interaction effect between the digital economy and rural industrial revitalization. However, regression coefficients alone do not denote specific causal relationships, necessitating further differential decomposition. The decomposition results, as shown in Table 9, indicate that the direct, indirect, and total effects of the digital economy are all significantly positive at the 5% level. This suggests that the digital economy has a spatial spillover effect on rural industrial revitalization, promoting not only local rural industrial revitalization but also influencing surrounding areas.

Table 8. Test results of the spatial spillover effects of the digital economy on rural revitalization.

Parameter	Coefficient
ρ	1.234 ** (2.707)
De	0.393 ** (6.641)
W (De_Spatial Lag)	0.290 ** (5.273)
Sample Size (n)	99
R^2	0.423
Adjusted R^2	0.405
F	F (3.95) = 20.456, p = 0.000

Note: ** denote significance levels of 5%. Standard errors are reported in parentheses throughout.

Table 9. Spatial effects analysis.

Item	Direct Effect	Indirect (Spillover) Effect	Total Effect
De	0.393 **	0.422 **	0.815 **

Note: ** denote significance levels of 5%. Standard errors are reported in parentheses throughout.

5. Conclusions and Suggestions

5.1. Conclusions

Based on the provincial panel data concerning the digital economy and rural revitalization in the Yangtze River Economic Belt from 2014 to 2022, the relationship between the digital economy and rural revitalization was constructed and the following conclusions were drawn:

(1) The digital economy has an impact on rural revitalization, its regression is significantly positive, and its rationality is verified by robustness test. In addition to the control variable of scientific and technological innovation, the other variables showed a positive effect.

(2) According to the heterogeneity analysis of the middle and lower reaches of the Yangtze River economic belt, the three regions are all positive at the 1% significance level, and the impact of the digital economy on rural revitalization is stronger in the upper and middle reaches than in the lower reaches.

(3) There is a spatial autocorrelation between the digital economy and rural revitalization, and there is a spatial spillover effect of the digital economy on rural revitalization in the Yangtze River Economic Belt.

It is worth noting that the research conclusions of this article are consistent with the research of some scholars [53,54], which proves the reliability of the conclusions of this article.

5.2. Suggestions

The positive effect of the digital economy on rural revitalization shows that the popularization of digital technology and the Internet can effectively promote rural development. The government and enterprises should continue to increase investment in digital infrastructure in rural areas, such as via broadband network construction and 5G technology promotion, so as to ensure that rural areas can enjoy the convenience and dividends brought

by the digital economy. At the same time, the deep integration of the digital economy and traditional industries is promoted. Traditional agriculture and handicraft industry are important parts of rural economy, and the development of the digital economy can inject new vitality into these traditional industries. For example, agricultural products can more easily enter urban markets through e-commerce platforms; through smart agriculture technology, agricultural production efficiency and product quality can be improved. Therefore, we should vigorously promote the integrated development of the digital economy and rural traditional industries to form a new economic growth point. At the policy level, the government should formulate and implement more detailed and targeted policies to support the deep integration of the digital economy and rural development. For example, if rural digital infrastructure construction, agricultural e-commerce development, rural digital entrepreneurship, and other fields were given tax incentives, subsidy support, and financing facilitation, this would support development. At the same time, in view of the negative role of scientific and technological innovation, policy makers should evaluate the effect of existing policies, adjust and optimize them in a timely manner, and ensure that scientific and technological innovation truly serves rural revitalization. Although technological innovation may have a negative effect on rural revitalization in some cases, this does not mean that technological innovation is not important. On the contrary, more attention should be paid to the adaptability of scientific and technological innovation in rural areas to ensure that technological innovation can effectively solve the problems faced by rural development, such as agricultural modernization and ecological environmental protection. This requires that in the process of scientific and technological innovation, the actual needs and conditions of the countryside are considered, and "tall" and ungrounded technical solutions should be avoided.

Secondly, according to the regional differences found in the research, the government needs to adapt to local conditions and make precise policies in terms of resource optimization allocation. According to the characteristics of different regions, it is important to promote a digital economy model that adapts to local needs. For example, the upstream region may need to develop more smart agriculture and ecotourism, while the midstream region can focus on agricultural e-commerce and rural industry chain extension. The government should increase policy support for the upper and middle reaches of the region, especially in terms of digital infrastructure construction, digital skills training, and digital agriculture promotion, and give more resources and financial support to further enhance the driving force of the digital economy for rural development in these areas. The upper and middle reaches show stronger potential in the impact of the digital economy on rural revitalization, indicating that there may be some innovative models or unique application scenarios in these regions. These regions should be encouraged to continue to explore and innovate, and to extend their success to downstream regions. At the same time, through inter-regional cooperation and resource sharing, the common development of the entire Yangtze River Economic Belt region will be promoted. For example, the digital economy experience in the upper and middle reaches can be extended to the downstream regions through the establishment of cross-regional platforms for digital economy cooperation.

In order to ensure the effective implementation and long-term effect of the policy, it is recommended to establish a sound monitoring and evaluation mechanism to regularly evaluate the actual impact of the digital economy and rural revitalization policy and its socioeconomic benefits. This will not only help achieve the timely adjustment of policy measures but will also provide a scientific basis and lessons for future policy making. At the same time, the government also needs to strengthen cooperation and communication with local governments, enterprises, and social organizations, form policy consensus and driving forces, jointly promote the organic combination of the digital economy and rural revitalization and achieve synergistic and comprehensive sustainable development of economic and social development.

5.3. Limitations

This study provides valuable insights but has limitations. The focus on the Yangtze River Economic Belt may affect the generalizability of findings to other regions. The discussion of implementation challenges, such as infrastructure and digital literacy, is limited and should be expanded. Additionally, the long-term sustainability of digital impacts and the translation of findings into actionable policies need further exploration. Future research should address these gaps to enhance the relevance and applicability of the results.

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