Review of Economic Assessment 2024 3 (1) 67-85

ANSER PRESS

Review of Economic Assessment

Homepage: https://www.anserpress.org/journal/rea

Does digital village construction contribute to improving food security?

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ABSTRACT

The issue of food security has become a global challenge, and it is therefore crucial to seek measures to ensure food security. As an emerging economic model, the digital economy is regarded as the most effective tool for the modernization of agricultural development. As a large food-producing country, China faces serious problems of agricultural non-point source pollution and food loss and waste. The purpose of this study is to explore the impact of digital village construction on food security. We measure the level of digital village construction and food security by entropy method and use the spatial Durbin model to analyze them. In this paper, we found that digital village construction facilitates food security not only in the region but also in neighboring regions. In addition, we found that the promotion effect is significant in main grain producing regions, while the opposite result is found in non-main grain producing regions. We hold that the application of the digital economy in the countryside has played an obvious role in promoting food security in main grain producing provinces, and provides important experimental evidence for reference to ensure food security in the future.

KEYWORDS

Food security; Digital village construction; Digital economy; Spatial Durbin model; Spillover effects

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ISSN 2972-3515
doi: 10.58567/rea03010005

Received 27 February 2024; Accepted 13 March 2024; Available online 14 March 2024

1. Introduction

Achieving sustainable global food security is one of the major challenges facing humanity today (West et al., 2014). The United Nations Millennium Declaration, adopted at the United Nations Millennium Summit in 2000, put forward the primary task of focusing on food security, and countries around the world have made many efforts to guarantee food security. However, the global food security situation remains very serious. According to data published by the Food and Agriculture Organization of the United Nations (FAO), in 2018, the number of people suffering from food shortages was 820 million globally, and more than 2 billion others lacked steady access to safe, nutritious, and adequate food. Against the backdrop of trade protectionism, geopolitical conflicts, and intensifying climate change, global food security faces increased uncertainty (Tilman et al., 2011; van Dijk et al., 2021; Xiang et al., 2020). Emerging technologies brought about by the digital economy, such as blockchain, have become effective tools to ensure food security (Lee et al., 2023; Bai et al., 2023; Luo et al., 2023a), aiming to do so through the effects of universality (Lioutas et al., 2021) and network platforms (Viciunaite, 2023). To this end, to explore the impact of the digital economy on sustainable food and agriculture systems, this paper constructs an indicator system for digital village construction to analyze its impact on food security. This paper will provide an experimental basis for guaranteeing food security and policy recommendations for digital village construction.

As a main grain producing country, China feeds 18 percent of its population on 9% of the world's arable land and 6 percent of its fresh water. Since 2004, China has achieved nineteen consecutive years of bumper grain production, especially in the past eight years, when grain output has stabilized at more than 1.3 trillion catties. However, China's food production still suffers from spatial fragmentation, poor infrastructure, high transportation costs, serious pollution of agricultural land, and prominent food losses and waste (Luo et al., 2023b; Hu et al., 2023), posing a great threat to food security (Holden and Ghebru, 2016; Liu and Zhou, 2021). Therefore, food security cannot be measured by yield availability alone, but also by factors such as the stability of food production, the sustainability of arable land, and rural fiscal utilization efficiency (Pinstrup-Andersen, 2009; Tu et al., 2023). However, intensive production methods in agriculture have not only resulted in inefficiencies in food production capacity (Gathala et al., 2020) but have also caused a great deal of agricultural non-point source pollution (Schaffner et al., 2011), a phenomenon that is particularly evident in rural areas. In addition, poor infrastructure in rural areas results in reduced food availability and an inability to cope with food shortages caused by climate change or emergencies (O'Hara and Toussaint, 2021). Fortunately, digital village construction is critical to filling this gap, which is essential to guarantee food security and support sustainable food and agriculture systems.

After agricultural and industrial economics, the digital economy is the most important economic type (Hu, 2023), which is the key to reducing the urban-rural income gap and sustainable development (Zhang, 2022; Bai et al., 2023). The digital economy, marked by emerging technologies such as big data, cloud computing, and 5G communications, brings opportunities for agricultural production and is critical to driving food security (Ahmed and Broek, 2017). In 2022, China's Ministry of Agriculture and Rural Development and five other major departments jointly issued the Key Points for Digital Rural Development 2022, which explicitly pointed out that it is necessary to construct a digital wall for food security. Therefore, strengthening the information monitoring of sustained agricultural output and supply has become the top priority for ensuring food security. At present, digital technology has been widely used in storage, circulation supervision, big data, safety supervision, and other aspects (Ding et al., 2022; Hu et al., 2023a; Xi et al., 2021). Digital villages utilize the Internet, big data, and other modern information technologies to promote agricultural and rural development and improve rural production and living conditions. In addition, the construction of digital villages ensures food security by reducing the information gap, precise control, and intelligent supervision (Cai et al., 2023).

The main objective of this article is to investigate whether the construction of digital villages is conducive to food security. This aim holds significant importance for maintaining food security under uncertain circumstances. The marginal contribution of this paper are as follows: First, the paper succeeds in identifying key means to achieve the goal of food security by integrating digital elements into sustainable food and agriculture systems from a digital economy perspective. Second, the impact of digital village construction on ensuring food security is analyzed through theory and empirical evidence to provide new ideas for achieving the stable development of food security. Finally, this paper incorporates spatial factors and explores the spillover effect of digital village construction from the perspective of guaranteeing food security, which provides practical references for building sustainable food and agriculture systems and realizing global food security.

The rest of the paper is organized as follows: section 2 provides a comprehensive review of the relevant literature. Section 3 provides a theoretical analysis and formulates hypotheses. Section 4 details the construction of relevant indicators and elaborates on the data used. Section 5 gives the empirical results. Section 6 discusses the findings. Finally, we summarize the paper and provide policy implications.

2. Literature review

Food security was first defined in terms of supply-side constraints as the “availability of food”(Devereux et al., 2020). As the discussion on food security deepened, the scope of food security research diverged, with some scholars focusing on national and international perspectives (Asche et al., 2015), while others argued that it needed to be explored at the household and individual levels (Upton et al., 2016). As far as food security assessment is concerned, some scholars assess food security from a single perspective, such as the food supply, demand, production, marketing coordination, food self-sufficiency, and food policy (He et al., 2017; Howden et al., 2007). As economic volatility and climate change intensify, an increasing number of scholars are focusing on multidimensional food security assessments (Schmidhuber and Tubiello, 2007). Qi et al. (2013) assessed food security in terms of three dimensions: quantity security, quality security, and sustainability. Jones et al. (2013) described food security in terms of four dimensions: food availability, food access, food utilization, and stability, with a greater focus on the quality of food security and health and nutrition. Clapp et al. (2022) expanded the conceptual framework of food security to include agency and sustainability in the analytical framework of food security. Global food security faces additional uncertainties as trade protectionism, geopolitical conflicts and climate change intensify. Scholars are gradually shifting their attention to how to improve food security capacity, such as ecological agriculture (Kerr et al., 2021), institutional and technological change (Huang and Yang, 2017), irrigation technology application (Kang et al., 2017), blockchain technology application (Feng et al., 2020), land use change (Winkler et al., 2021), and the participation of social capital (Nosratabadi et al., 2020), which is crucial measures to facilitate food security.

The digital economy, which aim to utilize big data to direct resources to play a role (Guo et al., 2023), is a new economic dynamic that promotes high-quality economic development. The rise of the digital economy is conducive to the improvement of industrial structure and is also a new driving force for sustainable economic development (Tan et al., 2023). It has been pointed out that the application of digital technology in the rural sector is conducive to enhancing farmers’ incentives to cultivate food and has an important impact on the quality and efficiency of agricultural production (Shen et al., 2022). Digital village construction empowers rural entities and rural governance through networking, informatization, and digitization (Cao et al., 2022; Leong et al., 2016).

Zhao et al. (2022) constructed a theoretical framework of digital rural construction for sustainable rural development based on the theory of digital empowerment in five dimensions: industry, ecology, culture, service, and governance. Based on county-level statistics, Chen et al. (2022) discovered that digital rural construction had a large favorable influence on farmers' family income. Tang and Chen (2022) showed that digital rural construction had a spatial spillover effect on the green transformation efficiency of arable land use. Zhang et al. (2023) discovered that the carbon abatement impact of digital villages is mostly dependent on the decrease of chemical fertilizers and pesticides, and that rural human capital is a limitation for digital rural building to enable green agricultural growth. Wang et al. (2022) emphasized the subjective welfare effect of digital literacy in digital village construction. Zhou et al. (2023) argued that digital village construction builds rural collective mutual aid and trust through network economic linkages.

To summarize, the existing studies may have the following gaps: first, most of the studies on food security still start from a single aspect, such as increasing food production, while few topics from a multidimensional perspective, such as stability, accessibility, and sustainability. Second, most of the studies on the digital economy and food security focus on the theoretical level, while there is a lack of empirical research, and even fewer scholars have explored the impact on food security based on the perspective of digital village construction. Third, the analytical framework of incorporating spatial factors into the digital economy on food security needs to be expanded. This paper fills these three research gaps.

3. Theoretical analysis and research hypotheses

The construction of the digital village is a process of structural change that reconstructs agricultural and rural development with modern digital information technology, providing a solid foundation for guaranteeing food security (Jiang et al., 2022). On the one hand, digital technology is useful for strengthening information sharing and interaction among the various links of the daily food industry chain, taking the construction of e-commerce platforms and information technology infrastructure as a breakthrough point, and promoting the dynamic balance of the relationship between the food supply and demand (Guo et al., 2021). On the other hand, digital village construction uses the application of big data, blockchain, drones, and other technologies to promote food production to “refinement”, “greening” and “reductio” (Benyam et al., 2021).

First, the digital economy is characterized by diminishing marginal costs and increasing marginal benefits, with cumulative value-added (Hu et al., 2023b). Digital village construction promotes industrial integration by utilizing the resource accumulation and high permeability of digital technology (Li et al., 2022). The high permeability of digital technology into the food industry has broadened and extended the food industry chain, realized the resource agglomeration effect and scale economy effect of food production, expanded food production, and enhanced the resilience of the food system (Lin and Li, 2023). In addition, digital village construction has brought digital infrastructure, breaking the isolated state of the local grain system, and connecting the food supply side and the consumer side in a timely and accurate manner through the information network platform, thus shortening the ineffective information transmission in the food supply chain and enhancing the ability of multiple subjects to promote food security through short chains (Mei et al., 2022). With the help of the network connection effect of digital technology, the production side can transmit the information of food supply to the sharing platform to monitor food price fluctuations in real-time, thereby reducing or eliminating the “data island effect” (Li et al., 2023).

Second, the construction of the digital village promotes a high degree of integration between digital technology and agricultural production, which is mainly reflected in the preproduction, mid-production, and postproduction of food production stages (Kamble et al., 2020). The penetration of digital technology helps to achieve precise planning and formula sowing before grain production, growth monitoring, pest and disease monitoring, precise irrigation during production, and automated harvesting after production (Rotz et al., 2019). The allocation of factor inputs should be optimized through precise fertilizer application, accurate fertilization, and drip irrigation technology to improve the grain yield, quality, and nutrition per unit of arable land area, thus alleviating the situation of nutrient-less and inefficient grain production (Fan et al., 2020). In addition, digital village construction accelerates the cultivation of smart agriculture, green agriculture, and other innovative forms of business, and promotes the transformation of food production to “refinement”, “greening” and “reduction”, thus enhancing the sustainability of arable land (Wang and Tang, 2023). Digital technology promotes the transformation of traditional agriculture into mechanization, dynamization, and digital integration so that food crops can realize intelligent management of water, fertilizer, temperature, light source, gas, pests, and diseases in the production process, achieve precision in the processing process, and realize consumer demand orientation in the marketing process (Klerkx et al., 2019).

The first law of geography states that everything is connected, and the closer the spatial proximity is, the stronger the connection (Tobler, 1970). Many studies have also pointed out that the economic and production activities of a region are often inseparable from neighboring regions (Zhu et al., 2023; Chen et al., 2023; Zhu et al., 2022). Therefore, the food security in a region is largely influenced by the level of food security in neighboring regions. At the same time, digital village construction, as the practice of the digital economy in rural areas, can generate trickle-down and diffusion effects with the help of digital technology, break through the inherent geographic limitations of rural areas, and promote the cross-regional flow of factors such as capital, technology, and labor. Specifically, relying on modern information technologies such as the Internet and big data, digital rural construction has optimized the construction of rural infrastructure and the precise layout of food production, greatly alleviating the problem of food shortages in the region and surrounding areas. In addition, digital village building has improved the ability of farmers to receive new information and the level of agricultural production technology, which not only improves the efficiency of food production in the region but also effectively solves the problem of technological shortages.

Therefore, this study proposes the following hypothesis:

H1: The construction of the digital village not only promotes food security in the region but also has positive spatial spillover effects that can also facilitate food security in neighboring regions.

4. Method

4.1. Indicator construction

4.1.1. Indicator construction for food security

Due to the rich connotation of food security, using a single indicator to measure it will cause inaccuracy. Therefore, this paper refers to the study of Jones et al. (2013) to construct a comprehensive capacity indicator system for food security from four aspects: food supply capacity, food accessibility, food stability, and farmland sustainability. Considering the availability of data, a total of 11 indicators are selected, as shown in Table 1. The entropy weight method was also utilized to measure the level of food security, and the data were mainly obtained from the statistical yearbook of Chinese provinces as well as the China Rural Statistical Yearbook.

In measuring the composite indicators, the entropy method is utilized to objectively determine the weights of the indicators. The specific steps are as follows.

Table 1. The indication selection of the level of food security.

Indication	Variables	Definition	Attributes	Weight
Food supply capacity	Production per unit area (ten thousand tons/km2)	This indicator reflects a province's grain production capacity and refers to the proportion of the province's total grain production in the current year in relation to the total area of the province.	+	0.2192
	Proportion of arable land area (%)	Cultivated land is the basic resource for food production, expressed as the ratio of the area of cultivated land for food in a province to the area covered by that province.	+	0.1893
	Financial support to agriculture (%)	The strength of financial support for agriculture reflects the importance that local governments attach to agricultural development, and is expressed as the ratio of a province's total financial support for agriculture to the province's total financial expenditure.	+	0.0684
	Agricultural machinery power (ten thousand kilowatts)	Agricultural machinery power is the embodiment of the application of modern technology in agricultural production and is expressed by the sum of the rated power of all agricultural machinery power in a province.	+	0.2338
Food accessibility	Per capita food consumption (ten/person)	This indicator reflects the extent to which provincial food supply meets demand, as measured by the ratio of total food production to resident population.	+	0.2058
Food Stability	Volatility coefficient of food production (%)	This indicator represents the instability of food production in the provinces and is expressed as the difference between food production and average food production as a ratio of average food production.	-	0.0079
	Volatility coefficients for food disasters (%)	Grain damage largely determines grain production for the year and is expressed as the difference between the area of grain damage per unit of sown area and the average of this value divided by the average of the grain damage area per unit of sown area.	-	0.0107
Farmland sustainability	Pesticide application rate (ton/kilo-hectare)	Overuse of pesticides could seriously affect the sustainability of arable land, expressed as a ratio of pesticide application to the area sown to crops.	-	0.0239
	Fertilizer application rate (ten thousand tons/kilo-hectare)	Fertilizer application contributes to increased food production, but excessive fertilizer inputs lead to unsustainable cropland, expressed as the ratio of fertilizer application to the area sown to crops.	-	0.0205
	Usage of plastic film (ton/kilo-hectare)	This indicator is expressed as the ratio of plastic film use to crop area.	-	0.0205

- Standardization of data. Maintaining consistency of the indicators in terms of magnitude, the data for the indicators involved were standardized using the linear dimensionless method:

For the positive indicators make the following changes:

$$y_{ij} = \frac{x_{ij} - x_{min}}{x_{max} - x_{min}} \tag{1}$$

For negative indicators make the following changes:

$$y_{ij} = \frac{x_{max} - x_{ij}}{x_{max} - x_{min}} \tag{2}$$

Where them, x_{min} and x_{max} represent the minimum and maximum values of indicator i, respectively, and x_{ij} and y_{ij} represent the original and normalized values of the indicator, respectively, where i=1,2，..., m indicates the number of years, and j=1,2， ..., n indicates the number of indicators.

- Calculation of indicator weights p_{ij}:

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \tag{3}$$

- Calculating information entropy e_j:

$$e_j = -k\sum_{i=1}^{m} p_{ij} ln p_{ij} \tag{4}$$

where the larger e_j is, the larger the information entropy of the j metric is, and the smaller its corresponding information.

- Calculate the information utility value d_j:

$$d_j = 1 - e_j \tag{5}$$

- Calculate the weights of the indicators w_i:

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} = \frac{1 - e_j}{\sum_{j=1}^{n}(1 - e_j)} \tag{6}$$

4.1.2. Indicator construction for digital village construction

Currently, scholars have not yet formed a unified standard for measuring the level of digital village construction, which is mainly divided into single indicators and comprehensive indicators. The single indicator is mainly measured by the number of farmers' mobile phone ownership, and the comprehensive indicator measurement mainly involves the four aspects of rural digital infrastructure, rural economic digitization, rural governance digitization, and rural life digitization. However, the impact of digital village construction on food security is mainly reflected in the construction of information platforms, digital production and life applications, and other levels. This paper constructs a comprehensive evaluation index system for digital village construction that includes three dimensions: information infrastructure construction, financial infrastructure construction, and service platform construction. Considering the availability of data, six secondary indicators are finally selected and measured using the same method as the above measurement of food security, as shown in Table 2.

Table 2. The indication selection of the level of digital rural construction.

Indication	Variables	Definition	Attributes	Weight
Information infrastructure development for digital villages	Internet infrastructure development	Expressed in terms of rural broadband access per 10,000 households used.	+	0.1616
	Smartphone penetration rate	Measured using average mobile phone ownership per 100 rural households.	+	0.0516
Digital Rural Financial Infrastructure Development	Breadth and depth of digital financial inclusion coverage	Measured using the Peking University Digital Financial Inclusion Index (2011-2020).	+	0.0450
Construction of a digital village service platform	Rural logistics coverage	Expressed using the length of rural delivery routes (km)	+	0.0668
	Rural e-commerce	Use the number of Taobao villages to indicate this.	+	0.6750

4.2. Model setting

4.2.1. Spatial correlation test

In this paper, the global Moran index is employed to test the spatial correlation of food security levels. The specific formula is as follows:

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(x_i - \bar{x})(x_j - \bar{x})}{s^2 \sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}} \tag{7}$$

where I is the global Moran index, taking the value range of [-1,1]. I>0 shows a positive spatial correlation, and the higher the value, the stronger the geographic correlation. I<0 denotes a negative spatial correlation, with the smaller its value indicating a higher geographic difference; I=0 denotes spatial stochasticity. $s^2=\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2$ is the sample variance. x_i is the level of food security in region i; W_{ij} is the spatial weight matrix. We choose the distance-based spatial matrix to test the effect of digital village construction on food security.

4.2.2. Spatial econometrics model

The results of the theoretical analysis suggest that there may be spatial spillover effects between the level of digital village construction and food security. Therefore, we utilize the spatial econometric model to analyze the impact of the digital village construction on food security. The form of the model is as follows:

$$SAFE_{it} = \beta_0 + \rho W_{it} SAFE_{it} + \alpha_1 Digital_{it} + \beta_1 W_{it} Digital_{it} + \alpha_2 Con_{it} + \beta_2 W_{it} Con_{it} + v_i + c_t + u_{it} \tag{8}$$

$$u_{it} = \varphi W u_{it} + \varepsilon_{it} \tag{9}$$

where $SAFE$ is the level of food security; Digital is the level of digital village construction; Con is the relevant control variable; i and t represent the province and time; ρ is the spatial autocorrelation coefficient of the level of food security; W is the spatial weight matrix; v is the individual effect; c is the time effect; u is the random perturbation term; and φ is the spatial autocorrelation coefficient of the random perturbation term.

4.3. Variable selection and data description

(1) Explained Variable. In the study, the primary explanatory variable is *SAFE*.

(2) Explanatory variable. We set the core explanatory variable as *Digital*.

(3) Control variable. Regional economic level (*PerGDP*): Expressed using regional GDP per capita. Level of human capital (*Hum*): To calculate rural human capital, we use the average rural educational attainment. We define illiterate and semi-illiterate students, elementary school, middle school, high school, secondary school, and college and above as 1, 6, 9, 12, and 15.5 years of schooling, respectively. Furthermore, the *Hum* is calculated by multiplying the number of persons at each stage by the number of years of schooling and then dividing by the total number of people. (3) Urbanization level (*City*): We utilize the measure of nonfarm employment as a percentage of the total population. (4) Infrastructure level (*Level*): We use the ratio of road mileage to the land area of the province as a measure. (5) Industrial structure (*Ind*): Expressed as the ratio of primary sector output to total output. (6) Agricultural cropping structure (*Str*): We use the value of plantation output as a share of GDP.

A descriptive analysis of the relevant variables is displayed in Table 3.

Table 3. Descriptive analysis of variables.

Variable	N	Mean	Std.	Min	Max
SAFE	300	0.316	0.157	0.073	0.745
Digital	300	0.116	0.117	0.011	0.895
PerGDP	300	5.599	3.88	1.323	36.298
Hum	300	8.539	0.858	6.361	11.188
City	300	0.649	0.128	0.317	0.958
Level	300	1.909	15.178	0.086	263.007
Ind	300	0.098	0.052	0.003	0.261
Str	300	0.29	0.086	0.105	0.552

4.4. Data sources

We mainly focus on the impact of digital village construction on food security in 30 provinces and municipalities (excluding Hong Kong, Macao, and Taiwan) from 2011-2019, which the data are mainly derived from the China Statistical Yearbook, the China Rural Statistical Yearbook, the Peking University Digital Inclusive Finance Index (2011-2019), the Alibaba Research Institute China Taobao Village Research Report, and the statistical yearbook of the 30 provinces and municipalities (excluding Tibet, Hong Kong, Taiwan, and Macao).

5. Result

5.1. Impact of digital village development on food security

5.1.1. Basic facts

Figure 1 demonstrates the digital village development from 2010 to 2019. We find that the process of digital village development in general exhibits a year-by-year growth trend. Specifically, the process of digital village construction was slow from 2010 to 2013, while it entered a phase of rapid development between 2014 and 2019. In addition, the development level of digital village building in the eastern area is significantly greater than the national average, while it is lower in the central and western regions, presenting an overall pattern of a decreasing gradient of “east-middle-west”. Figure 2 provides the trend of the time-series evolution of food security in China. From the national level, the level of food security development was low during the sample period, showing

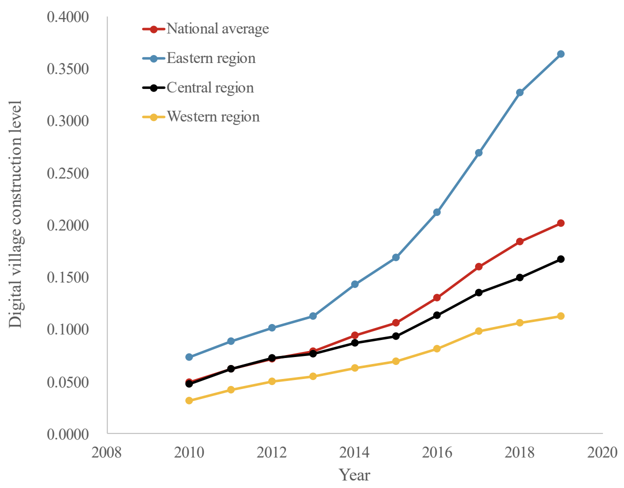

Figure 1. Trends in the level of digital village construction from 2010 to 2019.

significant volatility. In recent years, food security issues have become prominent due to the impact of extreme weather. We find that the central region has the highest degree of food security, followed by the eastern region, and the lowest in the western region. The provinces with higher levels of food security are located in the main grain producing areas, mainly because China has strictly controlled grain production, processing, transportation, and storage through the establishment of a pilot grain producing area, which has continuously optimized the capacity of grain supply and guaranteed agricultural land. Overall, China's food security has been on a slow upward trend.

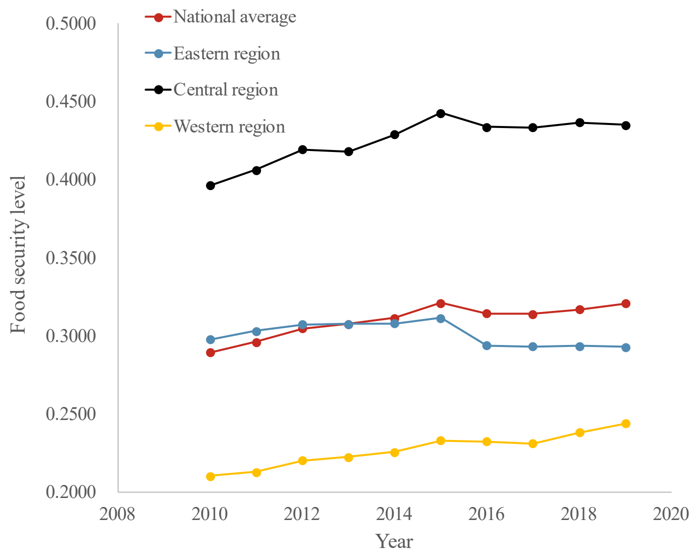

Figure 2. Trends in the level of food security in China from 2010 to 2019.

5.1.2. Spatial correlation test between digital village construction and food security

In this paper, we employ Stata16.0 to measure the global Moran index of digital village construction and food security, and the results are presented in Table 4. The global Moran index of food security capacity is significantly positive at the 1% level, indicating a significant positive spatial correlation of food security.

Table 4. Spatial correlation test for food security.

Variables	Moran's I	p-value
2010	0.477***	0.000
2011	0.472***	0.000
2012	0.464***	0.000
2013	0.466***	0.000
2014	0.451***	0.000
2015	0.453***	0.000
2016	0.440***	0.000
2017	0.436***	0.000
2018	0.424***	0.000
2019	0.420***	0.000

5.1.3. Analysis of the spatial effects of digital village construction on food security

Before conducting the empirical test, the LM test, LR test, Wald test, and Hausman test were first conducted to determine which spatial econometric model to choose, and the results are shown in Table 5.

Most of the LM test statistics are significant at the 1% level, indicating that the choice of spatial measurement model is justified. The LR test statistics are all significant at the 1% level, strongly rejecting the original hypothesis, and indicating that the SDM cannot be degenerated into the SAR model or the SEM. The Wald test statistic is also significant at the 1% level, suggesting that the choice of the SDM model is preferable to the SEM and SAR models.LR The time effect of the time-space effect test rejects the original hypothesis at the 1% level, demonstrating that it is more effective to use the time-fixed effect model when choosing the SDM model. Based on this, it is more effective to choose the time-fixed effects spatial Durbin model for analysis in this paper.

Table 5. Test results of the spatial measurement model.

		Value	P-value
LM test	Moran's I	3.705	0.000
	LM-lag	10.643	0.001
	Robust-LM-lag	0.003	0.956
	LM-error	11.130	0.001
	Robust-LM-error	0.490	0.484
LR test	LR-SDM/SEM	136.80	0.0000
	LR-SDM/SAR	137.45	0.0000
Wlad test	Wald-SDM/SEM	167.29	0.0000
	Wald-SDM/SAR	76.66	0.0000
Spatio-temporal fixed effects test	LR-both/ind	19.41	0.3671
	LR-both/time	816.02	0.0000

The fixed effects spatial Durbin model was estimated using Stata 16.0 and the spatial geographic distance matrix based on latitude and longitude was selected for analysis. The results are shown in Table 6. Regarding the core explanatory variables, the coefficient of the direct effect of digital village construction on food security is 0.475, the coefficient of the spatial lag term is 1.828, and it is significantly positive at the 1% level, which reveals that the construction of digital villages improves food security not only in the region but also in neighboring regions. On the one hand, the construction of digital villages improves food security through real-time food production safety monitoring and precise fertilizer and pesticide application, thereby enhancing the stable supply and sustainability of food in the region. On the other hand, digital village construction increases the application scenarios of digital technology in villages, realizes the cross-regional flow of production factors, and solves the problems of food supply and access in neighboring regions in a timely and rapid manner, thus enhancing the food security of neighboring regions. Therefore, H1 is verified.

Table 6. Regression results of digital village construction and food security.

Variables	Coefficient	Variables	Coefficient
Digital	0.475***	*W*Digital*	1.828***
	(5.240)		(3.300)
PerGDP	-0.004	*W*PerGDP*	-0.029
	(-1.420)		(-1.560)
Hum	-0.054***	*W*Hum*	0.118
	(-3.970)		(1.390)
City	0.212**	*W*City*	3.214***
	(2.210)		(5.940)
Level	0.002***	*W*Level*	0.014**
	(3.930)		(2.120)
Ind	0.931***	*W*Ind*	0.469
	(4.710)		(0.340)
Str	0.655***	*W*Str*	2.696***
	(5.590)		(4.120)
R2	0.0854		
Log-likelihood	224.7508		
N	300		

*Notes: t-value are shown in brackets; ***, ** and * means showing significance in 10%, 5%and 1%.*

5.2. Spatial effects decomposition

To further analyze the spatial effect of digital village construction on food security, the total effect is divided into direct effects and indirect effects using a partial differential solution, and the results are shown in Table 7. The total effect of digital village construction on food security is 4.227, which is significantly positive at the 1% level, indicating that a 1% increase in the level of digital village construction can increase the level of food security by 4.227%, of which the direct effect is 0.559, and the indirect effect is 3.668, which are both significantly positive at the 5% level, indicating that the construction of digital villages has a spatial spillover effect on food security. In the future, digital rural construction should continue to promote the in-depth integration of digital rural construction with agriculture and rural areas, give full play to the high penetration and universality of digital technology, improve the level of digital construction in each region, and expand the effectiveness of digital rural construction in promoting food security.

Table 7. Decomposition of spatial effects of variables under the spatial Durbin model.

Variables	Direct effect	Indirect effect	Total effect
Digital	0.559***	3.668**	4.227***
	(2.780)	(2.460)	(2.810)
PerGDP	-0.005	-0.051	-0.056
	(-1.270)	(-1.120)	(-1.250)
Hum	-0.048	0.153	0.105
	(-1.620)	(0.570)	(0.400)
City	0.329	6.058***	6.387***
	(1.530)	(2.820)	(2.780)
Level	0.003***	0.029*	0.032***
	(4.040)	(1.940)	(2.030)
Ind	1.005**	1.597	2.602
	(2.070)	(0.410)	(0.650)
Str	0.768***	5.351**	6.119***
	(3.070)	(2.160)	(2.330)

*Notes: t-value are shown in brackets; ***, ** and * means showing significance in 10%, 5%and 1%.*

5.3. Robustness testing

To further confirm the reliability of the results, we conduct a robustness test by adding control variables and replacing the weight matrix, and the results are shown in Table 8. First, the proportion of government financial support for agriculture (*Fs*) shows the local government's attention to agricultural development. Adding this control variable makes the model closer to reality, and we adopt the proportion of local agricultural subsidies to government financial expenditures to represent it. Second, we choose the spatial matrix based on the square of spatial distance to conduct spatial regression analysis again. The results all indicate that the conclusion that digital village construction can make the grain industry chain more resilient both in the region and neighboring regions is robust.

Table 8. Robustness testing.

Adding control variables				Spatial matrix based on distance squared			
Variables	Coefficient	Variables	Coefficient	Variables	Coefficient	Variables	Coefficient
Digital	0.478***	*W*Digital*	1.822***	*Digital*	0.430***	*W*Digital*	0.460**
	(5.080)		(3.150)		(5.270)		(2.380)
PerGDP	-0.004	*W*PerGDP*	-0.029	*PerGDP*	-0.001	*W*PerGDP*	-0.007
	(-1.380)		(-1.520)		(-0.110)		(-1.170)
Hum	-0.052***	*W*Hum*	0.113	*Hum*	-0.048***	*W*Hum*	0.015
	(-3.550)		(1.260)		(-3.690)		(0.520)
City	0.215**	*W*City*	3.274***	*City*	0.121	*W*City*	1.253***
	(2.200)		(5.890)		(1.420)		(6.740)
Level	0.002***	*W*Level*	0.014**	*Level*	0.002***	*W*Level*	0.005
	(3.950)		(2.120)		(3.720)		(1.570)
Ind	0.878***	*W*Ind*	0.773	*Ind*	0.773***	*W*Ind*	0.183
	(3.840)		(0.510)		(4.020)		(0.380)
Str	0.658***	*W*Str*	2.696***	*Str*	0.639***	*W*Str*	0.993***
	(5.280)		(3.830)		(6.260)		(4.930)
Fs	0.175	*W*Fs*	-0.484				
	(0.440)		(-0.170)				
R2	0.6374			R2	0.2284		
Log-likelihood	224.8661			Log-likelihood	239.3133		
N	300			Obs.	300		

*Notes: t-value are shown in brackets; ***, ** and * means showing significance in 10%, 5%and 1%.*

6. Discussion

China is a vast country with abundant resources, and there are large differences in economic, social, and agricultural development in different regions. The primary grain producing regions have better agroecological efficiency than the main grain marketing areas and areas with balanced grain production and marketing (Yang et al., 2022). To investigate if there is regional variability in the influence of digital village building on food security, separated into grain producing and non-grain producing areas, using spatial econometric modeling, empirical tests were carried out, and the results are displayed in Table 9. Within the main grain producing areas, the construction of digital villages improves food security. The direct impact coefficient is 0.295 and the coefficient of the spatial lag term is 0.653, both of which are significantly positive at the 10% level, demonstrating that the construction of digital villages can improve food security within the main food producing areas. The construction of digital villages has increased the application scenarios of digital technology in rural areas, broadened and extended the food industry chain, realized the resource agglomeration effect and the economy of scale effect of food production, expanded food production, and promoted the level of food security in the main grain producing areas. In addition, digital villages have brought about the development of digital infrastructure to break down the isolation of the local food system and reduce food shortages in the immediate provinces, thereby improving food security in the immediate region.

Within non-grain producing regions, digital rural development has reduced food security levels. The reason for this opposed result may be that within non-grain producing regions, despite higher levels of the digital economy, the opportunity cost of agricultural production is greater, leading to a higher proportion of non-farm employment, which reduces the potential willingness to produce food in the region, to the detriment of food security. In addition, non-grain producing regions tend to be more economically developed, and by attracting labor from nearby regions, although they raise the level of nonfarm employment, they may cause problems such as abandonment of agricultural land and shortages in food production, therefore lowering the level of food security in nearby regions.

Table 9. Heterogeneity analysis.

	Major grain producing area		Non-grain producing areas	
Variables	Coefficient	Coefficient	Coefficient	Coefficient
Digital	0.295*	0.653*	-0.085**	-0.239***
	(1.790)	(1.660)	(-1.980)	(-5.930)
Control variable	YES	YES	YES	YES
R2	0.2639		0.4864	
Log-likelihood	119.2586		302.9556	
N	130		170	

*Notes: t-value are shown in brackets; ***, ** and * means showing significance in 10%, 5%and 1%.*

7. Conclusions and implications

7.1. Conclusions

In this study, we explore the impact of digital village construction on food security by constructing a spatial econometric model based on panel data from 30 provinces in China from 2010 to 2019, and the conclusion follows.

(1) The building of digital villages has a positive geographical spillover impact on the level of food security, and it not only adds to the level of food security in the region but also supports the level of food security in nearby regions.

(2) There is significant regional heterogeneity in the impact of digital village construction on food security. In the main grain producing regions, the construction of digital villages improves food security in the region and its immediate neighbors due to scale effects and technology spillover effects. In non-grain producing regions, digital villages are obstacles to food security in the region and its immediate neighbors due to the increase in nonfarm employment.

7.2. Policy implications

The policy recommendations of this study are as follows:

First, the construction of rural digital infrastructure should be promoted. By vigorously developing the digital economy and vigorously promoting digital technology, we can effectively match the supply and demand information in the production and marketing links, unblock the channels of grain and oil production and marketing, and open up the two marketplaces of the key grain production and marketing areas. Furthermore, the government should increase its investment in digital infrastructure, especially in rural areas, to ensure the coverage of technologies such as the Internet, the Internet of Things, and satellite communication. This will facilitate real-time monitoring of agricultural production processes, enhance the transmission speed of agricultural information, provide farmers with precision agricultural technology, and thereby improve the grain yield and the production efficiency.

Second, the construction of digital villages is reasonably guided to provide strong support for guaranteeing food security through the penetration of digital information technology. The proactive utilization of digital village construction promotes the effective integration of the vertical extension of the food industry, the expansion of horizontal lines, and the penetration of digital technology to enhance food security. Additionally, there should be an encouragement of collaboration between agricultural research institutions, enterprises, and farmers to develop and promote digital agricultural technologies suitable for rural areas. For instance, intelligent agricultural management systems, unmanned aerial vehicle spraying of pesticides, and driverless agricultural machinery can enhance agricultural production efficiency, reduce the use of pesticides, and lower costs of agricultural production, thereby ensuring food security.

Third, different development strategies need to be formulated according to local conditions and interregional cooperation should be strengthened. As digital village construction has a strong spatial spillover effect, it promotes the coordinated development of various regions, breaks down regional barriers, and guides the flow of food factors, to better utilize the role of digital village construction in improving food security. Furthermore, international cooperation and exchange in the field of digital agriculture should be pursued with other countries, sharing advanced technologies and management experiences. Through international collaboration, high-quality varieties and advanced technologies can be introduced to improve the grain yield and the production efficiency.

7.3. Limitations and future research directions

This study reveals the impact of digital village construction on food security, contributing to the guarantee of food security to a certain extent. However, there are still certain limitations that need to be broken through in future research. Firstly, this study uses the entropy method to measure the digital rural construction index and food security indicators. When incorporating indicators, it refers to the existing mainstream literature and the key issues of research as much as possible. However, some other dimensions that may affect the core variables may be missed. In the future, further exploration can be conducted to identify the key factors affecting digital rural construction and food security and incorporate them into the indicator construction model. Furthermore, this study primarily focuses on the impact of digital rural construction on local or regional food security. In the future, a more in-depth exploration can be conducted to reveal the intrinsic mechanism of its influence, further uncovering the “black box” of how digital rural construction affects food security.

Funding Statement

This research was funded by Minmin Huang of Program of “Xinmiao” (Potential) Talents in Zhejiang Province, grant number 2023R451035 and Yanhu Bai of Research Project of Wenzhou Science and Technology Bureau, grant number R20220035.

Acknowledgments

We thank the support by the Program of “Xinmiao” (Potential) Talents in Zhejiang Province (2023R451035) and Research Project of Wenzhou Science and Technology Bureau (R20220035).

Conflict of interest

All the authors claim that the manuscript is completely original. The authors also declare no conflict of interest.

Author contributions

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