

Research on the spatial spillovers and threshold effects of digital financial inclusion on agricultural economic resilience

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Abstract Agricultural economic resilience refers to the ability of the agricultural economic system to withstand external risks and achieve adaptive recovery and transformation, which is important for sustainable agricultural development. Differences in financial levels determine differences in agricultural economic resilience, as financial levels determine how quickly an industry recovers after a shock. The digital financial inclusion program is an important way for the Chinese government to provide financial assistance to agriculture, and it has helped stabilize agricultural production and resist external shocks. Therefore, elucidating the impacts generated by digital financial inclusion is conducive to promoting agricultural economic resilience. This study examines the spatial spillover and threshold effects of digital financial inclusion on agricultural economic resilience based on panel data from cities in the Yangtze River Basin, China, from 2011 to 2022. The results show that digital financial inclusion development in both local and neighboring regions can promote local agricultural economic resilience; there is a threshold effect and a significantly positive spatial spillover effect of digital financial inclusion on the promotion.

Keywords digital financial inclusion; agricultural economic resilience; middle and lower reaches of the Yangtze River; agricultural technology innovation

1 Introduction

With climate change and social development, external uncertainty shocks such as natural disasters, pests and diseases, and public events are increasing. Against this backdrop, improving the shock-coping capacity of agricultural economic systems, which has a similar connotation to "resilience", has become an increasingly important focus of agricultural development^[1]. Agricultural economic resilience refers to the ability of an agricultural economic system to withstand external risks and achieve adaptive recovery and transformational reengineering, in short, its ability to respond to external shocks in an integrated manner^[2-3]. Under the increasingly complex external environment, it is of great significance to explore the path to enhance agricultural economic resilience to promote the sustainable development of agriculture.

Differences in the financial environment are an important source of heterogeneity in economic resilience, and an adequate supply of financial capital allows industries to better adapt in response to shocks^[4]. However, the long lag in the development of agricultural and rural finance has left agricultural development exposed to significant financial exclusion^[5]. Digital financial inclusion can effectively break the reality of financial exclusion in agriculture and improve the current situation of insufficient supply and poor accessibility of agricultural finance^[6].

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Digital financial inclusion optimizes the financial support environment for agricultural economic activities and supports effective external changes in agriculture, thereby contributing to agricultural economic resilience^[7]. Therefore, promoting the development of digital inclusive finance is an important path to forging agricultural economic resilience, and it is of great practical significance to examine the characteristics of the impact of digital inclusive finance on agricultural economic resilience.

The middle and lower reaches of the Yangtze River are the priority areas for sustainable agricultural development in China. Economic resilience is a new concept and paradigm to promote sustainable economic development^[8], and it is representative to choose the middle and lower reaches of the Yangtze River as a sample region to identify the path to enhance agricultural economic resilience. In addition, the middle and lower reaches of the Yangtze River, as an important part of the Yangtze River Economic Belt, a major national strategic development region in China, have obvious advantages in promoting the development of digital inclusive finance^[9]. Moreover, the provinces in the middle and lower reaches of the Yangtze River have the characteristics of both developed and underdeveloped regions, so it is reasonable to choose this region as a sample to analyze the relationship between finance and agricultural development^[10]. Therefore, this study intends to take the middle and lower reaches of the Yangtze River in China as an example to deeply explore the characteristics of the impact of digital financial inclusion on agricultural economic resilience.

Studies related to the topic of this research include two main aspects. The first is the study of the connotation, measurement, and influencing factors of agricultural economic resilience. The concept of resilience, which originated in the field of ecology and was later introduced into the study of economic management^[11-12], refers to the ability of an economy to recover, regulate, and maintain upward mobility^[13]. Under the guidance of evolutionary economics, agricultural economic resilience is defined as the comprehensive ability of the agricultural economic system to resist, recover, and innovate in response to external shocks. Scholars have used economic resilience measures to measure agricultural economic resilience, including the indicator system method and the core variable method. measure agricultural economic resilience, due to the strong subjectivity of the selection of indicators has not yet formed a unified measurement system. For example, some studies are from the resistance, resilience, and reconstruction of three-dimensional construction of the indicator system^[1], while some studies are from the resistance and reconstruction of two-dimensional measurement^[14]. The core variable approach, which is based on a counterfactual framework and reflects the functioning of the economic system under external shocks through sensitivity indices of economic variables, is the basic paradigm for measuring economic resilience and has been widely used^[15]. For example, Song Min et al. selected agricultural labor productivity as the core variable to measure agricultural economic resilience^[16]. Based on the measurement results, the study points out that there are significant spatial correlation characteristics of agricultural economic resilience^[17-18]. It has been pointed out that the integration of rural industries, the digital economy, agro-technological innovation, the scale of the agricultural economy, the development of agricultural infrastructure, and financial support for agriculture have contributed to agricultural economic resilience^[1,14,16,19]. The second is research related to agricultural economic resilience empowered by digital inclusive finance. Digital inclusive finance enables incremental replenishment of funds for agricultural economic activities and enhances agricultural economic resilience by promoting the integration of rural industries^[7]. Some scholars

have implicitly recognized the resilience-enhancing effects of digital financial inclusion in agriculture based on the digital economy perspective^[3,16]. In addition, studies have examined the application of digital financial inclusion to agriculture from different perspectives. From the perspective of agricultural production, digital financial inclusion promotes factor mobility and technology diffusion to increase total factor productivity in agriculture^[20]. From the perspective of agricultural business, digital inclusive finance can provide financial support for innovation and improvement of products and technologies to enhance agricultural business performance^[21]. Some scholars have pointed out that the development of digital inclusive finance has obvious stage and spatial characteristics and exhibits non-linear impacts and spatial spillover effects on farmers' income and agricultural development^[22,23,24,25].

In summary, existing research has provided ideas for examining the relationship between digital financial inclusion and agricultural economic resilience, but there is still some room for expansion. First, the existing research mainly focuses on the linear impact of digital financial inclusion on agricultural economic resilience, but the two have their own spatial correlation and dynamic changes in the characteristics of the study has not yet in-depth examination of digital financial inclusion on agricultural economic resilience of the non-linear impact of the spatial spillover mechanism; Second, most of the existing research is based on the perspective of the provincial region to carry out, and the development of agriculture has a high degree of natural dependence, and there are large differences in the internal development of the agricultural provincial region. Secondly, most of the existing studies are based on the provincial perspective, while agricultural development has a high degree of natural dependence, and there are also large differences in agricultural development within the provinces, so reducing the scale of the study is conducive to mitigating the impact of the differences in regional agriculture, so as to obtain more accurate and representative conclusions. These two points are the entry points of this study. Therefore, this study takes prefecture-level cities in the middle and lower reaches of the Yangtze River as samples, applies spatial panel models and panel threshold models, considers the spatial spillover mechanism of digital financial inclusion on agricultural economic resilience and its threshold effect characteristics, and systematically examines the complex impacts of digital financial inclusion on agricultural economic resilience, with the aim of providing empirical evidence for the formulation of policies related to the enhancement of agricultural economic resilience through the promotion of digital financial inclusion.

2 Theoretical analysis and research hypothesis

2.1 Analysis of the impact of digital financial inclusion on agricultural economic resilience

Financial development is a major power source for sustaining the economic system. As a new form of finance that focuses on long-tail groups such as farmers and agribusinesses, digital inclusive finance uses Internet technology to alleviate the financial constraints in all aspects of agricultural production and operation. Digital inclusive finance promotes the cultivation of agricultural economic resilience by providing incremental capital supplementation. Based on the perspective of resilience evolution, this study investigates the mechanism of the impact of digital financial inclusion on agricultural economic resilience from the three aspects of resistance, recovery, and reconstruction of the agricultural economic system.

First, the development of digital inclusive finance has improved the risk-resistant capacity of the agricultural economic system. On the one hand, the weak nature of agriculture makes the main

body of agricultural production and management face strong financing constraints, such as the high risk of agricultural production and the difficulty of establishing credit for the operation of agriculture-related enterprises, which impedes the development of agricultural mechanization and scale^[26]. Digital financial inclusion guarantees farmers fair access to financial resources and eases the credit financing constraints of agricultural entities^[27]. Digital inclusive finance enables farmers to innovate and optimize agricultural infrastructure through the provision of risk-controlled financing services, which in turn promotes the mechanization and scaling up of agriculture and effectively protects against the risks of agricultural production^[28]. On the other hand, raising the price of financial services is the main method by which brick-and-mortar financial institutions pass on their operating costs^[29]. Digital inclusive finance relies on Internet technology to provide financial services to farmers and provides agricultural entities with lower-cost financial services by reducing the time and space costs of financial institutions in providing services. Reducing the production and operation costs of agricultural entities will help to raise the level of their funds, thereby strengthening their risk-resistant ability.

Secondly, the development of digital financial inclusion enhances the resilience of the agricultural economic system. On the one hand, digital inclusive finance promotes the development of digital agricultural insurance, which provides financial compensation for agricultural entities that suffer economic losses. Agricultural insurance shares the economic losses of farmers and provides partial underwriting for the agricultural economic system^[20]. On the other hand, digital inclusive finance breaks the geographical limitation of financial services with the help of digital technology. The smooth flow of agricultural financial information has enhanced the convenience and timeliness of financial support for agricultural producers and operators when external shocks persist^[30], helping them to resume production and business.

Thirdly, the development of digital inclusive finance enhances the ability to transform and recreate the agricultural economic system. On the one hand, new agricultural economic entities are the backbone of agricultural transformation and upgrading^[31]. However, the cultivation of new subjects is difficult to realize only by their free funds, and credit constraints have become the main reason for hindering the cultivation of new agricultural management subjects^[32]. Digital financial inclusion is based on big data technology to realize accurate profiling of agricultural financing characteristics and efficient matching of financial resources^[33]. A diversified portfolio of financial products meets the different financing needs of agricultural entities, thus promoting the cultivation of new agricultural business entities and the transformation and upgrading of the agricultural economic system^[34]. On the other hand, the technological addition of digital financial inclusion reduces the difficulty of embedding Internet technology in agricultural production and business^[7]. "Digital business to promote agriculture" "live with goods" and other new forms of agriculture to enhance the added value of agricultural products, and promote the digital transformation of agriculture^[35].

Based on the above analysis, hypothesis H1 is proposed.

H1: Digital financial inclusion development will enhance agricultural economic resilience.

2.2 Spatial spillover effects of digital financial inclusion on agricultural economic resilience

The information flow theory of financial geography states that financial information has spatial spillovers, which means that local economic development can capture financial development benefits from its neighborhood^[36]. Digital financial inclusion in neighboring regions

has a dynamic impact on local agricultural economic activities. On the one hand, digital financial inclusion itself has spatial correlation and agglomeration characteristics, and the development of digital financial inclusion in neighboring regions promotes the development of local digital financial inclusion through the exchange of financial information and the sharing of digital technology between regions^[37]. Digital financial inclusion provides economic underpinning for agricultural activities, thus playing an energetic role in fostering local agricultural economic resilience. On the other hand, digital inclusive finance is directly embedded in the process of building new agricultural production and management bodies, agricultural equipment, and technology innovation by providing financial capital and digital technology for agricultural economic activities. The strengthening of the dynamics of change in the agricultural industrial structure helps to optimize the local agricultural industrial structure^[38]. Whereas agriculture has a high degree of natural dependence, there is a positive spatial correlation between the optimization of agricultural structures between neighboring cities^[39]. With the optimization and upgrading of the agricultural industrial structure in neighboring places, the local agricultural industrial structure will also be adjusted and optimized. The optimization of the agricultural industrial structure path provides structural support for the transformation and upgrading of the agricultural economic system under external shocks and promotes the cultivation of local agricultural economic resilience.

Based on the above analysis, hypothesis H2 is proposed.

H2: There is a positive spatial spillover effect of digital financial inclusion on agricultural economic resilience.

2.3 Threshold effects of digital financial inclusion on agricultural economic resilience

Metcalf's Law states that network externalization makes digital products exhibit the non-linear characteristics of diminishing marginal cost and explosive value growth^[40]. The theory of financial excesses states that excessive financial development will generate negative externalizations such as risk spillovers. These negative externalizations are detrimental to economic growth, implying that the relationship between financial development and economic growth is not simple and linear, but rather complex and non-linear^[41]. Digital inclusive finance, as one of the important carriers of digital technology-enabled financial systems, has both network externalities and financial attributes, and the impact effect of digital inclusive finance on agricultural economic resilience may also present a non-linear threshold characteristic under the combined effect of positive and negative externalizations.

On the one hand, as a typical product of the digital economy, digital inclusive finance uses Internet data as a key production factor^[42]. The replicability and mobility of Internet data elements make them cheaper to use than traditional material elements, and the expanding digital marketplace has led to geometric growth in the size of its users^[43]. The resulting economies of scale and scope further reduce the cost of data factor usage, which in turn tends to exhibit increasing factor rewards^[44]. With the continuous development of digital inclusive finance and its advancement in the agricultural and rural sectors, the scale of agricultural production and management entities seeking digital inclusive financial services has also grown. Under the role of incremental remuneration of data factors, the scale effect and economy of scope formed by the development of digital financial inclusion itself makes the cost of credit for agricultural subjects further reduce, and more significantly alleviate the agricultural financial constraints^[45]. Thus, the

contributory effect of digital financial inclusion on agricultural economic resilience is likely to show a marginal incremental trend.

On the other hand, the nature of financial products of digital inclusive finance determines that it has financial attributes. The continuous development of the financial system optimizes the efficiency of resource allocation in the real economy and can promote economic growth. However, finance itself is highly risky. Excessive financial development is not conducive to the effective regulation of its risks and can generate price bubbles, thus creating negative externalities on economic growth^[41]. As digital financial inclusion continues to develop, cross-cutting financial products continue to emerge. The hybrid cross-border operation of these products has made it more difficult to regulate financial risks. Risk spillovers may occur when the degree of development of digital financial inclusion exceeds a certain threshold. Moreover, digital inclusive finance mainly serves financially vulnerable groups such as farmers. These groups have relatively low financial literacy and weak awareness of risk prevention and security. When the level of digital inclusive finance development is overly detached from the level of acceptance of the main body of agriculture, it may further increase the risk of their financial use, thus adversely affecting agricultural economic resilience.

Based on the above analyses, as digital financial inclusion develops, its positive externalization on agricultural economic resilience is likely to show a marginal incremental growth trend. However, when the development of digital inclusive finance exceeds a certain threshold, its negative economic externalization begins to emerge and offset the original positive externalizations to a certain extent. Therefore, under the combined effect of positive and negative externalizations, the promotion effect of digital inclusive finance on agricultural economic resilience may present a certain threshold characteristic.

Based on the above analysis, hypothesis H3 is proposed.

H3: The facilitating effect of digital financial inclusion on agricultural economic resilience is characterized by thresholds.

3 Models, Variables, and Data Sources

3.1 Models

First, a benchmark regression model is constructed to examine the linear effect of digital financial inclusion on agricultural economic resilience:

$$RES_{it} = \alpha_0 + \alpha_1 DFI_{it} + \sum_{n=2} \alpha_n X_{nit} + \delta_i + \varphi_t + \varepsilon_{it} \quad (1)$$

where RES_{it} is agricultural economic resilience in the city i in year t , DFI_{it} is the level of digital financial inclusion in the city i in year t , X is a control variable, δ_i 、 φ_t are individual and time fixed effects, and ε_{it} is the error term.

Second, a spatial Durbin model is constructed to explore the spatial spillover effects of digital financial inclusion on agricultural economic resilience:

$$RES_{it} = \beta_0 + \beta_1 DFI_{it} + \sum_{n=2} \beta_n X_{nit} + \partial_1 WDFI_{it} + \sum_{n=2} \partial_n X_{nit} + \eta WRES_{it} + \delta_i + \varphi_t + \varepsilon_{it} \quad (2)$$

where W is the spatial weight matrix. In this study, the spatial neighborhood matrix is constructed based on the geographical location between the cities.

$$\omega_{ij} = \omega_{ji} = \begin{cases} 1, & \text{if region } i \text{ is adjacent to region } j \\ 0, & \text{if region } i \text{ is not adjacent to region } j \end{cases} \quad (3)$$

Finally, to examine the threshold characteristics of digital financial inclusion affecting agricultural economic resilience, a general form of panel threshold model is constructed:

$$RES_{it} = \lambda_0 + \lambda_1 DFI_{it} \times I(DFI_{it} \leq \theta) + \lambda_2 DFI_{it} \times I(DFI_{it} > \theta) + \sum_{n=3} \lambda_n X_{nit} + \delta_i + \varphi_t + \varepsilon_{it} \quad (4)$$

where θ is the unknown threshold value, I is the indicator function (taking the value of 1 when the constraints in parentheses are satisfied, and 0 otherwise).

3.2 Variables

3.2.1 Agricultural economic resilience (RES)

The core variable approach, which examines the key functions of an industrial-economic system by comparing regional and territory-wide trends, has been widely used^[15]. GDP provides an intuitive picture of economic development and is often used as a core variable to measure economic resilience. Therefore, this study mainly draws on Martin et al.'s study^[13] to select the value added of the primary sector as the core variable of agricultural economic resilience and measure its sensitivity index to gauge agricultural economic resilience in each city. The formula is as follows:

$$RES_{it} = \frac{\Delta E_{it} - (\Delta E_{it})^e}{|(\Delta E_{it})^e|} \quad (5)$$

$$(\Delta E_{it})^e = E_{i,t-k} g_{r,t} \quad (6)$$

where RES_{it} is the assessed value of agricultural economic resilience of city i in year t , ΔE_{it} , $(\Delta E_{it})^e$ are the actual and counterfactual changes in the value added of the primary sector in city i from year $t-k$ to year t respectively, E_{it} is the value added of the primary sector in city i in year t , $g_{r,t}$ denotes the rate of change in value added in the primary sector from year $t-k$ to year t for the whole of the study area, set $k=1$.

3.2.2 Digital financial inclusion (DFI)

Peking University's Digital Inclusive Finance Index has systematically constructed a digital inclusive finance evaluation index system from three dimensions: breadth of coverage, depth of use and degree of digitization, providing important data support and quantitative tools for China's digital inclusive finance research. The index is the most influential and widely used index for measuring digital inclusive finance^[46]. Referring to Zhong Kai et al.'s study^[47], this study does logarithmic processing on the digital financial inclusion index.

3.2.3 Control variables

First, the level of agricultural economy (AGP). The level of the agricultural economy directly affects the space for financial reserves and strategic choices in all segments of agricultural economic activities^[1], which in turn affects agricultural economic resilience. The level of the agricultural economy is measured by the ratio of value added in the primary sector to the number of people employed in the primary sector. The second is the level of urbanization (URB). The advancement of the urbanization process may have an impact on agricultural mechanization, scale, and intensification by influencing the urban-rural mobility of agricultural factors of production, which in turn may have an impact on agricultural economic resilience^[1]. The level of urbanization is measured by the share of the urban population in the total population. Third, government support (GOV). GOV provides support for the cultivation of good agricultural varieties, the application of advanced technology, and the construction and maintenance of infrastructure, which in turn affects agricultural economic resilience^[14]. The strength of government support is measured by fiscal expenditure on agriculture, forestry, and water. Fourth, the urban-rural income gap (UIG). The urban-rural income gap may have an impact on the quality of agricultural production and operations by affecting the retention of rural labor, which in turn has an impact on

agricultural economic resilience^[3]. The urban-rural income gap is measured as the ratio of the difference between the disposable income per capita of urban and rural residents to the disposable income per capita of rural residents.

3.3 Data Sources

This study takes 73 prefecture-level cities in the middle and lower reaches of the Yangtze River as the sample area, and the study period is 2011-2022. Data derived from Peking University's Digital Inclusive Finance Index^[48], China Statistical Yearbook^[49], statistical yearbooks of provinces (cities) in the middle and lower reaches of the Yangtze River, and authoritative website reports. Missing values were filled in by interpolation. To reduce the effect of extreme values, a bilateral 2% shrinkage was done for the explanatory variables and the core explanatory variables. The descriptive statistics results of the main variables are shown in Table 1, the maximum value of VIF is 2.31 and the mean value is 1.77, indicating that there is no significant multicollinearity among the variables.

Table 1 Descriptive statistics of variables

Variable	Symbol	Mean	SD	Min	Max
Agricultural economic resilience	RES	- 0.009	1.323	- 4.509	3.248
Digital financial inclusion	DFI	5.213	0.502	3.751	5.808
Level of urbanization	URB	0.590	0.118	0.331	0.896
Level of agricultural economy	AGP	0.360	0.252	0.068	1.765
Level of government support	GOV	0.452	0.369	0.023	4.187
Urban-rural inequality	UIG	1.179	0.370	0.558	3.276

4 Results and discussion

4.1 Benchmark regression analysis

The test of the linear relationship of the model is the basis for examining the presence of non-linear features in the model^[50]. Therefore, the linear effect of digital financial inclusion and agricultural economic resilience as described by the baseline regression model was first estimated. The Hausman test results significantly rejected the original hypothesis, so this study chose the two-way fixed effect model for the estimation and the results are shown in Table 2.

Table 2 reports the regression results of the fixed effects model. The results show that the regression coefficients of DFI are all positive and passed the significance test, indicating that digital financial inclusion exhibits a significant positive impact on agricultural economic resilience. Combined with the theoretical analysis, digital inclusive finance enables agricultural production and management subjects to have equal and convenient access to financial resources, so it guarantees the supply of funds for agricultural economic activities (such as infrastructure construction, mechanization, scale-up, and other activities). The robust financial chain mitigates the risk of financial chain breakage that may occur in the agricultural economic system due to external shocks. At the same time, digital financial inclusion has led to the embedding of digital technology in the agricultural production and operation chain, which has improved the allocation of agricultural resources and the efficiency of production and operation. The embedding of digital technologies has stimulated new forms of agriculture and enhanced the risk-resistance and repair and innovation capacity of the agricultural economic system under external shocks, thus promoting the cultivation of agricultural economic resilience.

The coefficient of AGP is positive and passes the significance test, indicating that the level of the agricultural economy has a contributing effect on agricultural economic resilience. A broad agricultural economic base provides sufficient financial security for all segments of agricultural economic activities and enhances agricultural economic resilience by expanding the space for agricultural choices in the face of uncertainty shocks. The coefficient of UIG is positive and passes the significance test, indicating that there is a facilitating effect of the urban-rural income gap on agricultural economic resilience, which is similar to the findings of Zeng Long et al. [51] As the income gap between urban and rural areas continues to rise, the proportion of the rural labor force participating in non-farm employment has gradually increased, indirectly boosting the non-farm income of rural residents. Higher incomes favor agricultural capital deepening and increase agricultural resilience to risk [51], thereby contributing to agricultural economic resilience.

Table 2 Benchmark regression results

Variable	(1)	(2)
DFI	0.242* (0.123)	1.026* (0.563)
AGP	0.389 (0.292)	0.826** (0.385)
GOV	0.111 (0.298)	0.194 (0.333)
URB	- 0.731 (1.135)	- 0.823 (1.310)
UIG	0.940*** (0.238)	0.896*** (0.226)
_cons	- 2.140** (0.811)	- 5.206** (2.396)
Id	yes	yes
Year	no	yes
N	876	876

Note: *, **, and *** indicate statistically significant at 10%, 5%, and 1%, respectively; robust standard errors in parentheses.

4.2 Robustness tests

This study uses the following methods for robustness testing. First, the regression model was replaced with a random effects model. Second, the core explanatory variable DFI is replaced with the breadth of coverage index (COV). Third, the lagged term of DFI is introduced as an instrumental variable to mitigate the possible endogeneity problem. In the one-stage regression, the regression coefficient of L.DFI on DFI is positive and passes the significance test, and the F-statistic is > 10 , indicating that L.DFI passes the weak instrumental variable test. The results in Table 3 are consistent with the results of the benchmark regression, which suggests that the benchmark regression results are somewhat robust.

Table 3 Robustness tests

Variable	Replacement model	Replacement of explanatory variables	Instrumental variable method
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DFI	0.161** (0.077)		2.639** (1.329)
COV		0.887*** (0.248)	
Control variable	yes	yes	yes
_cons	- 0.885* (0.503)	- 4.589*** (1.339)	- 18.133** (7.601)
<i>N</i>	876	876	803

4.3 Spatial spillovers of digital financial inclusion on agricultural economic resilience

4.3.1 Spatial autocorrelation test

Prior to the estimation of the spatial effects, the Moran' I index was chosen to perform a spatial autocorrelation test between the DFI and the RES. The spatial weight matrix used for this test was the spatial adjacency matrix. Table 4 reports the results of the spatial autocorrelation test. The results show that the Moran' I index for both DFI and RES is positive and passes the significance test, indicating that both exhibit significant spatial autocorrelation. Therefore, the choice of a spatial econometric model to examine the relationship between the two is reasonable.

Table 4 Spatial autocorrelation test

Year	DFI			RES		
	<i>I</i>	<i>Z</i>	<i>P</i>	<i>I</i>	<i>Z</i>	<i>P</i>
2011	0.614	8.202	0.000	0.167	2.540	0.006
2012	0.566	7.608	0.000	0.361	5.241	0.000
2013	0.572	7.695	0.000	0.386	5.344	0.000
2014	0.576	7.731	0.000	0.448	6.157	0.000
2015	0.573	7.704	0.000	0.125	1.878	0.030
2016	0.540	7.258	0.000	0.243	3.453	0.000
2017	0.535	7.202	0.000	0.657	8.832	0.000
2018	0.587	7.882	0.000	0.389	5.293	0.000
2019	0.597	8.011	0.000	0.556	7.551	0.000
2020	0.601	8.067	0.000	0.591	7.963	0.000
2021	0.636	8.510	0.000	0.411	5.682	0.000
2022	0.658	8.786	0.000	0.233	3.308	0.000

4.3.2 Spatial effects test

Commonly used spatial econometric models mainly include the spatial Durbin model (SDM), spatial lag model (SAR), and spatial error model (SEM). Among them, SDM can consider the spatial correlation between the explained and explanatory variables at the same time and is a general form of SAR and SEM. Therefore, in order not to lose the generality of the model selection, the SDM model is chosen in this study to test the spatial spillover effects of digital financial inclusion affecting agricultural economic resilience. Table 5 reports the results of the decomposition of the spatial effects of the impact of digital financial inclusion (DFI) on agricultural economic resilience. The results show that the total, direct, and indirect effects of DFI's impact on RES are all positive and pass the significance test. This indicates that digital

financial inclusion shows a significant positive impact on agricultural economic resilience when the spatial effect is taken into account, and both local and neighboring digital financial inclusion shows a significant positive impact on local agricultural economic resilience. Combined with the previous theoretical analyses, local digital inclusive finance promotes local agricultural economic resilience by alleviating the financial constraints and information constraints of local agricultural production and management entities. At the same time, the development of digital inclusive finance in neighboring regions also radiates to the local area through spatial spillovers, thus contributing to the cultivation of local agricultural economic resilience.

Table 5 Spatial effects decomposition results

Variable	Direct effect	Indirect effect	Total effect
DFI	1.658** (0.659)	1.737* (1.042)	3.395** (1.489)
Control variable	yes	yes	yes
rho			0.623*** (0.046)
sigma2_e			0.962*** (0.089)
<i>N</i>	876	876	876

4.4 Threshold Characteristics of digital financial inclusion affecting agricultural economic resilience

Based on the previous theoretical analyses, the promotional effect of digital financial inclusion on agricultural economic resilience may have stage differences. This study uses a panel threshold model to examine the threshold characteristics of digital financial inclusion affecting agricultural economic resilience. Before conducting the threshold regression, this study uses the DFI as the threshold variable and the triple threshold model to test the characteristics. The results in Table 6 show that the single-threshold and double-threshold effects of DFI passed the significance test, while the triple-threshold effect did not pass the significance test. This indicates that the effect of DFI on RES is not a simple linear relationship, but there is a double-threshold feature.

Based on the results of the threshold test, the double threshold model was chosen to test the threshold effect of digital financial inclusion on agricultural economic resilience, and the regression results are shown in Table 7. The results show that when the DFI is in different intervals, its coefficient on RES is positive, but the coefficient values differ. When DFI is below the first threshold, its coefficient estimate is 1.548 and passes the significance test. When the DFI is between the first and second thresholds, the coefficient estimate is 1.310 and passes the significance test. When the DFI is above the second threshold, the coefficient estimate is 1.742 and passes the test of significance. This suggests that the development of digital inclusive finance exhibits a facilitating effect on agricultural economic resilience, but the facilitating effect is characterized by non-linearity. When the level of digital inclusive finance is lower than the first threshold or higher than the second threshold, its promotional effect on agricultural economic resilience is more obvious, which is consistent with the results of the threshold characteristics test

of the study of Tian Lin et al. on the promotion of rural revitalization by digital inclusive finance [52].

Table 6 Threshold Characterization Test

Threshold variables	Number of thresholds	<i>F</i> value	<i>P</i> value
DFI	Single Threshold	52.96	0.000
	Double Threshold	22.08	0.030
	Triple threshold	18.01	0.493

Table 7 Threshold regression results

Variable	(1)
DFI (DFI \leq 5.321)	1.548*** (0.561)
DFI (5.321 < DFI \leq 5.363)	1.310** (0.568)
DFI (DFI > 5.363)	1.742*** (0.562)
Control variable	yes
_cons	- 7.314*** (2.400)
<i>N</i>	876

5 Conclusion

The purpose of this paper is to assess the spatial spillovers and threshold characteristics of digital financial inclusion in enhancing agricultural economic resilience. As such, we contribute to efforts to implement and build resilience in the agricultural economy. This study empirically analyses the spatial spillovers and threshold effects of digital financial inclusion affecting agricultural economic resilience using a sample of prefecture-level cities in the middle and lower reaches of the Yangtze River in China from 2011 to 2022. Our analysis shows that there is a promotion effect of digital financial inclusion on agricultural economic resilience, and this result has a certain degree of robustness. There is a positive spatial spillover effect of digital financial inclusion on agricultural economic resilience, which means that both local and neighboring digital financial inclusion development will enhance local agricultural economic resilience. As the level of digital financial inclusion increases, its boosting effect on agricultural economic resilience is characterized by a double threshold. Therefore, policy efforts aimed at enhancing the agricultural economic system's resilience to external shocks by strengthening infrastructure, improving incomes, and strengthening innovation should take into account the development of digital inclusive finance practices.

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