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The Impact of Digitalization on Agricultural Production Efficiency in China and its Spatial Spillover Effect

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Abstract

Based on panel data from 30 provinces in China from 2012 to 2023, this study further explored the impact of digitalization on agricultural production efficiency and spatial spillover effects by using the bidirectional fixed effects and the spatial Durbin model. Research conclusion: (1) Agricultural digitalization promotes the improvement of agricultural production efficiency; (2) Agricultural digitalization can enhance agricultural production efficiency through capital deepening and the extension of the industrial chain; (3) Agricultural digitalization in this region not only has an impact on the production efficiency of this region, but also has a stronger spatial spillover effect on the production efficiency of neighboring regions. Therefore, this study puts forward countermeasures and suggestions from aspects such as the data element market and the improvement of relevant policies.

Keywords

Digitalization of Agriculture; Spatial Durbin Model; Entropy Weight -TOPSIS Method.

1. Introduction

Agriculture is the fundamental industry of the national economy and the "ballast stone" for stabilizing the economy and society. Its healthy and stable development is of vital significance to the modernization process of the entire country. At present, the growth model driven by traditional elements in China's agriculture has approached its limit. With the full-domain penetration of digital elements, adjusting the development structure and transforming the development mode have become important tasks for the agricultural development (Xiaohong Chen, 2019). Under the background of the digital economy, the digital transformation of agriculture has become a key path to break through the bottleneck of factors and enhance production efficiency.

Agricultural digitalization is an inevitable choice to address multiple challenges such as population growth, resource constraints, climate change, and market competition. Its essence lies in reconstructing agricultural production methods through technology.In recent years, the intensity of policy support has continued to increase.Policy documents such as the "Digital Agriculture and Rural Development Plan (2019-2025)" has provided clear guidance and support for the digital transformation of agriculture. The No. 1 Central Document of 2025, "Opinions on Further Deepening Rural Reform and Steadily Promoting the Comprehensive Revitalization of the Countryside", further states that agricultural digitalization is a key path to promoting agricultural modernization and cultivating "new quality agricultural productivity". This provides policy support and direction guidance for the digitalization of agriculture. By digitizing agriculture to transform traditional agriculture and organically integrating digital elements with the entire agricultural process and the entire industrial chain, functions such as labor substitution, precise input, environmental monitoring, and intelligent decision-making can be achieved. This accelerates the deep integration of digital technology with the development of agriculture and rural areas, injects new vitality into agricultural development,

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and also provides new approaches to solving problems and challenges in agricultural development.

At present, on a global scale, digitalization has become an important trend in agricultural development.Countries around the world are increasing their investment in agricultural information technology, intelligent equipment and other aspects, using digital technology to promote the sustainable development of agriculture. Compared with Australia and Israel, China's agricultural digitalization started relatively late. Agricultural digitalization is confronted with problems such as high technical thresholds, great difficulty in promotion and a shortage of agricultural informatization talents. All these will restrict the further improvement of agricultural production efficiency. Therefore, studying the impact of agricultural digitalization on agricultural production efficiency is not only an urgent need to break through the bottleneck of agricultural development, but also a strategic choice to promote the modernization transformation of agriculture.

2. Theoretical Analysis and Research Hypotheses

2.1. The Impact of Digitalization on Agricultural Production Efficiency

The new economic growth theory expounds that technological progress and the accumulation of human capital are the two major engines of economic growth. Agricultural digitalization plays a significant role in promoting the development of social productive forces (Maosheng Yin, 1990). Technological changes have brought about tremendous changes in agricultural production techniques, farming methods and organizational forms, thereby enabling agricultural productivity to increase rapidly to a level that can promote industrialization and urbanization (Jie Yang, 1966). Agricultural digitalization is an important manifestation of agricultural technological transformation. Essentially, agricultural digitalization has promoted profound changes in agricultural production methods. This means that it has accelerated the accumulation and diffusion of knowledge and innovation, and unleashed the endogenous growth potential of productivity.The digitalization of agriculture not only brings about the optimal allocation of traditional production factors and an agricultural revolution, but more importantly, it has promoted new types of high-quality productive forces (Liang You and Xiangyu Tian, 2024). New quality productivity is not only the increase in the output of a single production factor, but also the improvement of total factor productivity (Tongshan Liu and Jie Liu, 2024). Agricultural digitalization can not only achieve the automation and intelligence of production, reduce the uncertainty of manual operation, improve the standardization and stability of production, but also lower the fluctuation of unit input-output. It can also promote the flow and optimal combination of agricultural production factors, empower traditional production factors, release the role of new factor resources, and further enhance the total factor productivity. Therefore, hypothesis H1 is proposed:

H1: Agricultural digitalization is positively promoting agricultural production efficiency.

2.2. The Influence Mechanism of Digitalization on Agricultural Production Efficiency

Agricultural digitalization reconstructs the agricultural production system through multi-dimensional paths, significantly enhancing production efficiency. Firstly, digitalization breaks the traditional agricultural equilibrium trap through capital deepening, embedding new types of capital such as data elements and intelligent equipment into the production system. It achieves a stepwise growth in productivity through intelligent substitution and the improvement of factor quality. Its influence depth surpasses that of mechanization transformation (Fan Gao, 2010). Secondly, the extension of the industrial chain builds a networked ecosystem. Technologies such as blockchain traceability connect the entire

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production and sales process. Through information transparency, transaction costs are reduced and product added value is increased (Ningning Guan et al., 2024), forming a Pareto improved resource realallocation mechanism. Therefore, this paper proposes the following two hypotheses:

H2a: Agricultural digitalization can enhance agricultural production efficiency through capital deepening

H2b: Agricultural digitalization enhances agricultural production efficiency through the extension path of the industrial chain

2.3. The Spatial Spillover Effect of Digitalization on Agricultural Production Efficiency

The endogenous growth theory describes that knowledge and technological innovation are the key factors driving economic growth. During the digital transformation process in this region, new knowledge and technologies can be generated. Agricultural producers in this region can learn and apply these advanced digital technologies. Through the technology diffusion and learning effect among regions, they can enhance their own production management level and also bring positive externalities to the agricultural production of neighboring regions, improving the production efficiency level of neighboring regions.Economic ties and factor flows among regions can also generate economies of scale and network effects.The scale effect leads to a decrease in the unit cost of digital infrastructure and services, and these benefits can be passed on through inter-regional connections.The network effect enables agricultural producers to better integrate into the digital production network, thereby obtaining the convenience of resources and information, and having a positive spatial spillover impact on the agricultural production efficiency of adjacent areas.Furthermore, digital technology itself has the attribute of breaking the limitations of time and space (Yiqi Wang and Haojuan Dong, 2025). Existing studies have proved that digital infrastructure has a positive spatial spillover effect on the total factor productivity of the surrounding areas (Wei Wang et al., 2018; Xiaogang He et al., 2023).The digitalization of agriculture is not merely the digitalization of infrastructure, but the digitalization of the entire industrial chain. It can break down spatial and geographical barriers, facilitate the free flow of production factors on a larger scale, optimize capital allocation, and form a positive spillover effect, thereby enhancing production factors.Based on this, research hypothesis H3 is proposed:

H3: Agricultural digitalization in this region not only has an impact on the production efficiency of this region, but also has a stronger spatial spillover effect on the production efficiency of neighboring regions.

3. Research Design

3.1. Model Design

(1) Bidirectional Fixed-effect Model

This study adopts a bidirectional fixed-effect model to construct the following econometric model for benchmark regression:

$$\ln AP_{it} = \alpha_0 + \alpha_1 \ln ADL_{it} + \alpha_{it} \sum \ln X_{it} + \eta_{it} + \xi_{it} + \mu_{it} \quad (1)$$

Among them, APit represents agricultural productivity; ADLit represents the level of agricultural digitalization; ∑Xit is the relevant control variable. α_0 , α_1 , α_{it} , η_{it} , ξ_{it} , μ_{it} are respectively the constant term, the regression coefficient of the level of agricultural

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digitalization, the regression coefficient of the control variable, the time fixed effect, the individual fixed effect, and the random error term.

(2) Mechanism Model

In this study, capital deepening and industrial chain extension are introduced as mechanism variables into the fixed effect model.

$$\begin{cases} \ln M_{it} = \alpha_0 + \alpha_1 \ln ADL_{it} + \alpha_{it} \sum \ln X_{it} + \xi_{it} \\ \ln AP_{it} = \chi_0 + \chi_1 \ln M_{it} + \chi_{it} \sum \ln X_{it} + \eta_{it} \end{cases} \quad (2)$$

Among them, APit represents agricultural productivity; ADLit represents the level of agricultural digitalization; M is the mechanism variable, includes the capital deepening, extension of the industrial chain; ∑Xit is the relevant control variable. α_0, χ_{it} is a constant term, α_1, χ_1 is the regression coefficient of the explained variable, α_{it}, χ_{it} is the regression coefficient of the control variable. ξ_{it}, η_{it} is the random error term.

(3) Spatial Econometric Model

In order to examine the spatial spillover effect of digitalization in neighboring regions on the efficiency of this region, this study intends to achieve it by constructing a spatial econometric model. The general form of the spatial econometric model is:

$$Y = \alpha + \beta X + \rho W_Y + \theta W_X + \lambda W_\mu + \varepsilon \quad (3)$$

Among them, Y is the agricultural production efficiency (AP), X is the agricultural digitalization (ADL) and the set of control variables, WY is the spatial effect of Y, WX is the spatial effect of X, Wμis the spatial effect of interference from different units. α is a constant term, β is the regression coefficient of the agricultural digitalization (ADL) and the set of control variables, ρ is the spatial autoregressive coefficient of Y, θis the spatial autoregressive coefficient of X, λ is the regression coefficient of the interference of different units, ε is the random error term. For the stability of the panel data, all variables are processed logarithmically.

3.2. Variable Selection

(1) Explained Variable: Agricultural Production Efficiency

This study estimates total factor productivity based on the Translog function. The commonly used Translog production functions in the random frontier are as shown in Formula 4.

$$\ln(Y) = \beta_0 + \Sigma\beta_i \ln(X_i) + 1/2 \Sigma \Sigma \beta_{ij} \ln(X_i) \ln(X_j) + v - u \quad (4)$$

Among them,Y is the total agricultural production value, Xi include the number of people employed in agriculture, forestry, animal husbandry and fishery(X1), total mechanical power(X2), application amount of chemical fertilizer(X3), effective irrigated area of crops(X4)and the total sown area of crops(X5), β_0, β_i, β_{ij} is the parameter to be estimated, v is the random error term, u is a non-negative inefficient term.

Refer to the research of Lili Yang and Shuai Shao(2014), Linglin Xiang(2014), Yaguang Hu(2019), etc, the stochastic frontier production function based on the Translog function applicable to this study is set as follows:

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$$\begin{aligned}\ln Y &= \beta_0 + \beta_1 \ln X1 + \beta_2 \ln X2 + \beta_3 \ln X3 + \beta_4 \ln X4 + \beta_5 \ln X5 \\ &+ \beta_t t + \beta_{11} \ln X1 \ln X1 + + \beta_{22} \ln X2 \ln X2 + \beta_{33} \ln X3 \ln X3 \\ &+ \beta_{44} \ln X4 \ln X4 + \beta_{55} \ln X5 \ln X5 + \beta_{tt} t^2 + \beta_{12} \ln X1 \ln X2 \\ &+ \beta_{13} \ln X1 \ln X3 + \beta_{14} \ln X1 \ln X4 + \beta_{15} \ln X1 \ln X5 \\ &+ \beta_{23} \ln X2 \ln X3 + \beta_{24} \ln X2 \ln X4 + \beta_{25} \ln X2 \ln X5 \\ &+ \beta_{34} \ln X3 \ln X4 + \beta_{35} \ln X3 \ln X5 + \beta_{45} \ln X4 \ln X5 \\ &+ \beta_{t1} t \ln X1 + \beta_{t2} t \ln X2 + \beta_{t3} t \ln X3 + \beta_{t4} t \ln X4 + \beta_{t5} t \ln X5 \\ &+ \nu - \mu\end{aligned} \tag{5}$$

(2) Explanatory Variable: Digitalization of Agriculture

Table 1. Weight Distribution of the Evaluation Index System for Agricultural Digitalization Level

First-level indicators and weights	Secondary indicators(Explanation of Secondary Indicators,Symbol)	Weight distribution	Attribute
Digital infrastructure construction (0.2127)	The popularization level of the Internet in rural areas (Number of Mobile Internet Users ,X1)	0.0413	+
	The level of rural Internet users (The number of Internet broadband access users,X2)	0.0492	+
	The coverage level of rural information and communication (Optical cable line length ,X3)	0.0490	+
	The popularity level of smart phones in rural areas (Mobile phone penetration rate,X4)	0.0180	+
	The level of agricultural logistics construction (Rural delivery route mileage ,X5)	0.0318	+
	Agricultural meteorological observation level (Number of agricultural meteorological observation stations ,X6)	0.0233	+
The digital production and management level of agriculture(0.1838)	Investment level in agricultural production (Fixed Asset Investment in Agriculture, Forestry, Animal Husbandry and Fishery ,X7)	0.0561	+
	Effective irrigated area in agriculture (The proportion of actual irrigated area to cultivated land area ,X8)	0.0337	+
	The number of agricultural information technology laborers (Number of people employed in the information transmission, software and information technology services industry ,X9)	0.0601	+
	The level of agricultural production mechanization (The proportion of total power of agricultural machinery to the total sown area of crops,X10)	0.0313	+
	The intensity of agricultural chemical fertilizer application (The proportion of agricultural chemical fertilizer application to the total sown area of crops ,X11)	0.0026	+
The level of digital operation in agriculture(0.2683)	The digitalization level of agricultural product information (Total volume of postal and telecommunications services ,X12)	0.0961	+
	The development level of e-commerce for agricultural products (Proportion of enterprises with e-commerce transaction activities ,X13)	0.0574	+
	The level of digital trading of agricultural products (E-commerce sales of agricultural products,X14)	0.1147	+
Agricultural digital industrialization(0.3352)	The quantity and scale of rural online payment (Rural Digital Inclusive Finance Index,X15)	0.0174	+
	The scale of digital bases for agriculture and rural areas (The proportion of Taobao villages among all administrative villages,X16)	0.2678	+
	The level of agricultural service orientation (The proportion of employed people in agriculture, forestry, animal husbandry and fishery services to the total employed people in agriculture, forestry, animal husbandry and fishery,X17)	0.0500	+

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This study refers to existing research(Yamin Han, 2024; Yuan Li and Wanchen Xiong et al., 2025; Pengshan Zhao, 2022; Pein Jiang, 2024). It is proposed to construct an evaluation index for the digitalization level of agriculture from the perspective of the entire agricultural industrial chain, includes four first-level indicators and 17 second-level indicators, namely digital infrastructure construction, digital production and management level of agriculture, digital operation level of agriculture, and digital industrialization of agriculture.The entropy weight-TOPSIS method was adopted to measure the level of agricultural digitalization. The construction of the index system and the index weights are shown in Table 1.

(3) Mechanism Variable

1)Capital Deepening: It is expressed as the ratio of the physical capital stock of the primary industry to the number of laborers in the primary industry.Regarding the calculation of the physical capital stock of the primary industry, the perpetual inventory method is adopted. In the actual calculation process, the depreciation rate is 10.96%, referring to the selection of Haojie Shan (2008).

2)Extension of the Industrial Chain: It is expressed by the output value of agricultural, forestry, animal husbandry and fishery specialties and auxiliary activities. It refers to the operating income generated from irrigation services, primary processing services of agricultural products, other agricultural services, forestry services, veterinary services, other animal husbandry services, fishery services, etc.

(4) Control Variable

In addition to the digitalization level of rural areas, there are also some other important variables that can have an impact on agricultural technological progress. Based on the research of Mingzhong Luo (2024), this study selects the intensity of fiscal support for agriculture, economic development level, urbanization rate, regional industrial structure, crop disasters rate and the level of opening up to the outside world as control variables.①The intensity of fiscal support for agriculture. It is expressed by the value of the local fiscal expenditure on agriculture, forestry and water affairs to the local fiscal general budget expenditure. ②Economic development level.It is expressed by the ratio of regional gross domestic product to the total population.③Urbanization rate.It is expressed by the proportion of the permanent resident population of the town to the total population.④Regional industrial structure.It is expressed by the ratio of the output value of the secondary and tertiary industries to the regional GDP.⑤Crop disaster rate.It is expressed by the ratio of the affected area of crops to the sown area of crops.⑥The level of opening up to the outside world.It is expressed as (total volume of imports and exports of goods * Exchange rate of the US dollar against the Chinese yuan)/Regional GDP.

3.3. Data Sources and Descriptive Statistics

The research subjects of this article are 30 regions in China (including provinces, municipalities directly under the Central Government and autonomous regions, excluding Hong Kong, Macao, Taiwan and the Tibet Autonomous Region), and the time range of the research is from 2012 to 2023. The data mainly come from the "China Statistical Yearbook", "China Rural Statistical Yearbook", "China Population and Employment Statistical Yearbook", "Statistical Yearbook of the Tertiary Industry", "China Labor Statistical Yearbook", as well as the official websites of the Alibaba Research Institute, the Digital Finance Research Center of Peking University, and the official website of the Ministry of Agriculture and Rural Affairs.The descriptive statistics of the variables are shown in the following table.

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Table 2. Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
AP	360	0.902	0.052	0.761	0.981
Digitalization of Agriculture	360	0.135	0.092	0.030	0.652
Capital Deepening	360	0.021	0.042	0.001	0.332
Extension of the Industrial Chain	360	193.694	188.816	4.600	1005.13
The intensity of fiscal support for agriculture	360	0.115	0.050	0.021	0.624
Economic development level	360	6.249	3.183	1.895	18.999
Urbanization rate	360	0.543	0.046	0.430	0.723
Regional industrial structure	360	0.905	0.052	0.749	0.998
Crop disaster rate	360	0.129	0.106	0.000	0.696
The level of opening up to the outside world	360	0.264	0.265	0.008	1.354

4. Empirical Analysis

4.1. Analysis of Benchmark Regression Results

Empirical analysis was conducted using STATA 17.0 software. The benchmark regression results are shown in models (1) and (2). The results indicate that, regardless of whether control variables are included or not, agricultural digitalization promotes the improvement of agricultural production efficiency. Thereby verifying that hypothesis H1 holds true.

Table 3. Benchmark Regression Results

Variable	(1)	(2)
	AP	AP
Digitalization of Agriculture	0.0478***(0.00579)	0.0638***(0.0048)
The intensity of fiscal support for agriculture		0.0190***(0.00711)
Economic development level		0.00667(0.00664)
Urbanization rate		-0.0280(0.0282)
Regional industrial structure		-0.616***(0.0420)
Crop disaster rate		-0.00427(0.00279)
The level of opening up to the outside world		0.00230(0.00343)
Constant	0.635(1.804)	2.149(1.560)
year	Control	Control
province	Control	Control
obvious	360	356
R-squared	0.259	0.558

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.

4.2. Mechanism Inspection

This study adopts the fixed effects model for mechanism testing. Agricultural digitalization has an impact on agricultural production efficiency through two mechanism paths: capital deepening, industrial chain extension.

(1) Capital Deepening

Models (1-1) and (1-2) in Table 4 present the empirical results. The coefficient of capital deepening in Model (1-1) is as high as 1.143 (p<0.01) . The explanatory power of Model R2 is as high as 70%, indicating that agricultural digitalization has a significant positive promoting effect on capital deepening. In Model (1-2), the coefficient of the impact of capital deepening on total factor productivity is 0.022 (p<0.01), indicating that capital deepening positively

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promotes the improvement of agricultural production efficiency. From the empirical results, agricultural digitalization enhances production efficiency through capital deepening. Suppose H2b is proved.

(2) The Extension of The Industrial Chain

Models (2-1) and (2-2) in Table 4 present the empirical results. The influence coefficient of agricultural digitalization on the extension of the industrial chain in model (2-1) is 0.684 ($p<0.01$). It indicates agricultural digitalization has a positive promoting effect on the extension of industrial chains such as agricultural product processing and agricultural services. Agricultural digitalization is not merely about the digitalization of the agricultural industry; it also involves promoting the digital industrialization of agriculture and enhancing the added value of agricultural products and services. Therefore, the extension of the industrial chain can serve as a key to the digital industrialization of agriculture. Model (2-2) examines the impact of industrial chain extension on agricultural production efficiency, with a coefficient of 0.0261 ($p<0.01$), indicates that the extension of the industrial chain positively promotes agricultural production efficiency. Combined with the empirical results, hypothesis H2c is proven, that is, agricultural digitalization can enhance agricultural production efficiency through industrial chain extension.

Table 4. Regression Results of the influencing mechanism

Variable	(1-1)	(1-2)	(2-1)	(2-2)
	Capital Deepening	AP	Extension of the Industrial Chain	AP
Digitalization of Agriculture	1.143***		0.684***	
	(0.0524)		(0.0422)	
Capital Deepening	0.0324			0.0261***
	(0.0639)			(0.00174)
Extension of the Industrial Chain		0.0220***	0.0324	
		(0.000965)	(0.0639)	
The intensity of fiscal support for agriculture	0.0705	0.0048***	0.00521	0.0062***
	(0.0486)	(0.00132)	(0.0391)	(0.00164)
Economic development level	0.128***	0.00255**	0.0356	0.0040***
	(0.0445)	(0.00121)	(0.0358)	(0.00150)
Urbanization rate	-0.0747	0.0168***	-0.259*	0.0238***
	(0.192)	(0.00523)	(0.155)	(0.00649)
Regional industrial structure	2.527**	-0.089***	3.759***	-0.0744*
	(1.134)	(0.0308)	(0.912)	(0.0391)
Crop disaster rate	-0.0385**	-0.001*	-0.0163	-0.002***
	(0.0190)	(0.000519)	(0.0153)	(0.000639)
The level of opening up to the outside world	-0.0530**	-0.002***	-0.0307*	-0.003***
	(0.0226)	(0.000618)	(0.0182)	(0.000760)
Constant	-2.243***	-0.000270	6.255***	-0.224***
	(0.208)	(0.00649)	(0.168)	(0.0112)
year	Control	Control	Control	Control
province	356	356	356	356
obvious	0.701	0.715	0.595	0.560

Standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

4.3. Spatial Spillover Effect

(1) Construction of Spatial Weight Matrix

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The research hypothesis mainly aims to explore the impact of digitalization in this region on the production efficiency of neighboring regions. Therefore, considering the comprehensive research content, this study mainly adopts the geographical distance weight matrix (Formula 6).

$$W_{ij} = \begin{cases} \frac{1}{dij} & ,i \neq j \\ 0 & ,i = j \end{cases} \quad (6)$$

Among them,i represents Region i, j represents Region j, W_{ij} is the geographical distance weight matrix, $d_{ij}$is the shortest road mileage from the provincial capital of Region i to that of Region j.

(2) Spatial Correlation Test - Moran Index

Before conducting spatial econometrics, a spatial correlation test is performed using the Moran index to verify whether the data can be spatially econometric. This inspection step is indispensable. More than 99% of the Moran index of agricultural production efficiency is positive, and all have passed the significance test of 10%. There is a positive correlation of agricultural production efficiency in space and spatial agglomeration, and it has passed the test.

Table 5. Results of spatial correlation Test

year	I	Z	year	I	Z
2012	0.021	1.523	2018	0.036 **	1.961
2013	0.027*	1.704	2019	0.047 **	2.274
2014	0.035**	1.932	2020	0.052 **	2.429
2015	0.044**	2.158	2021	0.082***	3.239
2016	0.037**	0.037	2022	0.117***	4.223
2017	0.037 **	0.037	2023	0.108***	3.958

(3) Optimal Model Selection

The LM test is conducted on the data to determine whether to choose the Spatial Durbin Model (SDM), the Spatial Lag Model (SAR), or the Spatial error Model (SEM). The LM test results of this study revealed (as shown in Table 6) that LM-log, LM-Error, Robust-LM-Error and Robust-LM-log were significant at the 1% level. All the values have passed the test, and considering comprehensively, SDM was initially selected for this study.

Table 6. LM Test Results

LM test	LM value	P value
LM-Error	553.879	0.000
Robust-LM-Error	200.904	0.000
LM-log	367.791	0.000
Robust-LM-log	14.815	0.000

To further confirm whether this study is more suitable for SDM, Wald tests and LR tests were conducted to determine whether this study would degenerate into a spatial lag model and a spatial error model if the spatial Durbin model was used (Wang Yiqi and Dong Haojuan, 2025). Table 7 shows that both the Wald test and the LR test have passed. Therefore, SDM is selected for this study.

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Table 7. Results of Wald test and LR test

Wald test and LR test	Estimated value	P value
LR spatial lag	71.75	0.000
Wald spatial lag	74.78	0.000
LR spatial error	68.60	0.000
Wald spatial error	73.10	0.000

(4) Hausman Test

After determining SDM to be used, it is still necessary to further judge whether the fixed effect or the random effect will be used in the subsequent research. Therefore, the Hausman test was adopted in this study for judgment. The Hausman test results indicated that the statistical values were significant at the 1% level. Therefore, the fixed effect was selected for this study. In order to determine which of the individual fixed effect, the time fixed effect and the bidirectional fixed effect among the fixed effects is more suitable for this study, the LR fixed effect was used to test the more appropriate type in this study. The research results show that the bidirectional fixed effect is superior to the temporal fixed effect and the individual fixed effect. Therefore, this study adopts the bidirectional fixed effect.

(5) Decomposition of Spatial Durbin Model and Analysis

The estimation results in Table 8 demonstrate the spatial spillover mechanism of agricultural digitalization on agricultural total factor productivity. Models (1)-(3) are the direct effect, indirect effect and total effect of the spatial Durbin model, respectively. Model (1) demonstrates the direct effect of agricultural digitalization on agricultural production efficiency, which is consistent with the benchmark regression results, that is, digitalization in this region positively promotes the improvement of agricultural production efficiency in this region. In Model (2), the coefficient of the level of agricultural digitalization is 24.24, which is significant at the 10% level. This indicates that the level of agricultural digitalization in this region will have a positive impact on the agricultural production efficiency of adjacent regions, that is, there is a spatial spillover effect. In Model (3), the coefficient of the level of agricultural digitalization has further increased, with a total effect of 25.17 and significant at the 5% level. This indicates that the comprehensive impact of agricultural digitalization is not only limited to the local area but also amplified into a regional growth driver through spatial correlation, exerting its positive externality effect. The empirical results of the spatial Durbin model verify Hypothesis H3, that is, the digitalization of agriculture in this region will have a spatial spillover effect on the agricultural production efficiency of neighboring regions, and it is positive.

Table 8. Decomposition and Estimation Results of the Spatial Durbin Model

Variable	(1)	(2)	(3)
	Direct effect	Indirect effect	Total effect
Digitalization of Agriculture	0.933*(1.390)	24.24*(12.62)	25.17**(12.58)
The intensity of fiscal support for agriculture	-0.0207(0.0286)	-0.0176(0.282)	-0.0383(0.288)
Economic development level	-0.0140(0.0335)	-0.599*(0.337)	-0.613*(0.334)
Urbanization rate	0.389***(0.144)	-3.112**(1.317)	-2.723**(1.290)
Regional industrial structure	1.505*(0.806)	48.70***(13.09)	50.21***(13.46)
Crop disaster rate	-0.0005(0.013)	0.0321(0.130)	0.0316(0.134)
The level of opening up to the outside world	-0.0284(0.0196)	0.247(0.154)	0.219(0.148)
year	Control	Control	Control
province	Control	Control	Control
obvious	360	360	360
R-squared	0.307	0.307	0.307

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.

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4.4. Robustness Test

This study intends to conduct robustness tests by using the variable replacement method and the sample size change method. The potential release of agricultural digitalization needs to take into account the gradualness of technological penetration. The development of agricultural digitalization usually does not take effect immediately in the current year and has a certain lag. Therefore, in this study, the digitalization level lagging by one period is adopted to replace the original agricultural digitalization level for the robustness test. In Model (1), the coefficient of the agricultural digitalization level lagging behind by one period was 0.0655($p<0.01$). This result verified the long-term effect of digitalization, that is, the application of technology does not have an immediate effect but requires time to penetrate into production practice. Prove the robustness of the original conclusion. In Model (2),, as 2019 to 2021 were years with a high incidence of the COVID-19 pandemic, the data were somewhat distorted compared to other years. Therefore, in this study, the data from 2019 to 2021 were excluded and the sample size was changed for robustness testing. The coefficient of the level of agricultural digitalization is 0.0618 ($p<0.01$), passing the robustness test.

Table 9. Results of robustness tests

Variable	(1)	(2)
	AP	AP
Digitalization of Agriculture	0.0655***(0.00503)	0.0618***(0.00586)
The intensity of fiscal support for agriculture	0.0153(0.0104)	0.0248***(0.00782)
Economic development level	0.00532(0.00751)	0.00495(0.00807)
Urbanization rate	-0.0332(0.0296)	-0.0218(0.0323)
Regional industrial structure	-0.586***(0.0432)	-0.630***(0.0508)
Crop disaster rate	-0.00267(0.00286)	-0.00925**(0.00360)
The level of opening up to the outside world	0.000380(0.00386)	0.00249(0.00432)
Constant	3.270*(1.813)	0.0618***(0.00586)
year	Control	Control
province	Control	Control
Observations	326	266
R-squared	0.546	0.563

Standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

5. Conclusion and Suggestions

Based on panel data from 30 provinces in China from 2012 to 2023, this study further explored the impact of digitalization on agricultural production efficiency and spatial spillover effects by using the bidirectional fixed effects and the spatial Durbin model. Combining theoretical analysis with empirical results, the following conclusions are obtained:(1) Agricultural digitalization positively promotes agricultural production efficiency. Digital technology promotes the improvement of agricultural efficiency throughout the entire chain from production, management to circulation by optimizing resource allocation, enhancing management accuracy and reducing losses.(2) Capital deepening and the extension of the industrial chain are the core mechanisms for improving the efficiency of agricultural digitalization at present. The overall trend is "capital deepening (with strong driving force and high explanatory power) > industrial chain extension (efficient but dependent on synergy).(3) Agricultural digitalization in this region not only has an impact on the production efficiency of this region, but also has a stronger spatial spillover effect on the production efficiency of

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neighboring regions, indicating that the efficiency improvement in adjacent areas has a mutually reinforcing effect.

In the context of the digital economy and in light of China's basic national conditions and regional differences, this study puts forward suggestions as four aspects: First, accelerate the digitalization of agriculture and improve the development mechanism of digital agriculture. In terms of the entire agricultural industrial chain, it is necessary to improve the development mechanism of digital agriculture and perfect the agricultural data collection system, covering data collection from all links of the agricultural industrial chain, including production, processing, circulation and sales. Encourage all types of agricultural entities to proactively collect data through sensors, intelligent terminals and other means, and establish a data reporting mechanism to make the entire process of agriculture from production to terminal sales transparent. This enables agricultural producers to promptly understand market prices and trends, and allows terminal consumers to fully understand information such as the origin and logistics of agricultural products, thereby solving the problem of information asymmetry in agriculture. Reduce the risks of agricultural production and the safety issues of agricultural products. Second, optimize the development path of agricultural digitalization and improve the digital factor market. In the era of digital economy, deepening capital and extending the industrial chain are key links in optimizing the digital development path of agriculture. By effectively integrating and utilizing digital resources, optimizing resource allocation, promoting the circulation of agricultural products, and strengthening the collaborative cooperation among all links in the industrial chain, agricultural production efficiency can be enhanced and the digital factor market can be further improved. Third, improve the cooperation mechanism among industry, academia and research in agricultural digitalization to stimulate the vitality of agricultural technological innovation. At present, the general human capital level of agricultural practitioners in our country is not high, and thus they have insufficient understanding and cognition of digital elements. The biggest obstacle to the promotion of the industry-university-research cooperation mechanism in the agricultural field is that agricultural practitioners "have no profit to make". Focusing on "profitable" agricultural supplies enterprises can more likely stimulate the innovative vitality of agricultural technology. It is easier to popularize and promote agricultural technological innovation through agricultural supplies enterprises than directly to agricultural practitioners. Fourth, improve relevant policies and systems to promote high-quality agricultural development. One of the major reasons for the relatively slow development of agricultural digitalization is the high initial investment cost. Therefore, for agricultural practitioners, whether in terms of ideology or economic situation, most of them maintain a wait-and-see attitude towards the development of agricultural digitalization, and few actively participate in it. This, in turn, limits the role of digital elements in the progress of agricultural technology. Therefore, the government should improve relevant policies and systems to promote high-quality agricultural development.

References

[1] Chen Xiaohong, Li Yangyang, Song Lijie, et al Theoretical System and Research Prospect of Digital Economy [J]. Management World, 2022,38 (02):208-224+13-16.

[2] Shan Haojie. Re-estimation of China's Capital Stock K :1952-2006 [J]. Journal of Quantitative & Technical Economics,2008,25(10):17-31.

[3] Gao Fan. Structural Transformation, Capital Deepening and the Improvement of Agricultural Labor Productivity: A Study Taking Shanghai as an Example [J] Economic Theory and Economic Management, 2010(2):8.

[4] Guan Ningning, Liu Lingyun, Huang Huichun. Has the development of the agricultural industrial chain improved agricultural production efficiency? -- Re-examination based on the Service Perspective [J]. Arid Land Resources and Environment,2024,38(07):13-21.

ISSN: 2692-7608 DOI: 10.6981/FEM.202505_6(5).0005

[5] Guan Ningning, Liu Lingyun, Huang Huichun. Has the development of the agricultural industrial chain improved agricultural production efficiency? -- Re-examination based on the Service Perspective [J]. Arid Land Resources and Environment,2024,38(07):13-21.

[6] Han Yamin. An Empirical Study on the Impact of Agricultural Digitalization Development on the Income of Agricultural Practitioners [D] Shandong University of Finance and Economics,2024.

[7] He Xiaogang, Guo Xiaobin,2023. Network Infrastructure, Knowledge Spillover and Urban Innovation: A Quasi-Natural Experiment from the "Broadband China" Strategy [J]. Economic Latitude and Longitude (1): 35-46.

[8] Hu Yaguang. Regional Evaluation and Deconstruction Analysis of China's Tourism Industry Efficiency: An Empirical Study Based on SFA [J] Contemporary Finance and Economics,2019(10): 107-119.

[9] Jiang Pein. Research on the Impact of Digitalization in China's Agriculture on Total Factor Productivity in Agriculture [D] Yunnan University of Finance and Economics,2024.

[10] Li Yuan, Xiong Wanchen, Ren Baoping. Regional Differences, Dynamic Evolution and Formation Mechanism of Agricultural Digitalization Level in China [J]. Economic and Management Review,2025,41(01):148-160.

[11] Liu Tongshan, Liu Jie. Has moderate-scale operation promoted the formation of new agricultural productive forces? -- Empirical Analysis Based on the Framework of "Productivity - Mode of Production - Labor Productivity" [J]. Reform, 2024(10).

[12] Luo Mingzhong, Wei Binhui. Digital Empowerment, Technological Progress and Common Prosperity in Rural Areas [J]. Journal of Agrotechnical Economics,2024(02):4-18.

[13] Wang Wei, Zhang Hao, Wang Feng,2018. Information Infrastructure, Spatial Spillover and Urban Total Factor Productivity [J]. Economic Latitude and Longitude (5):44-50.

[14] Wang Yiqi, Dong Haojuan. The Impact Mechanism and Spillover Effects of Digital Economy on Urban Carbon Emission Performance [J/OL]. Scientia Geographica Sinica,1-12[2025-03-12].

[15] Xiang Linglin Calculation of TFP Growth Rate in Western Regions Based on SFA Model and Its Efficiency Decomposition [J] Statistics and Decision,2017(03):152-155.

[16] Yang Jie. The British Agricultural Revolution and the Transformation of Agricultural Production Technology [J]. World History, 1996(5):11.

[17] Yang Lili, Shao Shuai, Cao Jianhua, Ren Jia Decomposition of Changes in Industrial Total Factor Energy Efficiency in the Yangtze River Delta Urban Agglomeration and Influencing Factors: An Empirical Study Based on Stochastic Frontier Production Function [J] Journal of Shanghai University of Finance and Economics,2014,16(03):95-102.

[18] Yin Maosheng On Agricultural Technological Transformation [J]. Rural Economy and Society, 1990(3):54-59.

[19] You Liang, Tian Xiangyu. Agricultural New Quality Productivity: Practical Logic, Connotation Analysis and Generation Mechanism [J]. Economic Issues, 2024(6).

[20] Zhao Pengshan Research on the Impact of Agricultural Digitalization Development on the Urban-Rural Income Gap [D]. Liaoning University,2022.