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How Digital Infrastructure Empowers Agricultural Total Factor Productivity—Based on a Moderated Mediation Effect Model

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Abstract

Based on panel data of 281 prefecture-level cities in China from 2006 to 2020, this paper constructs a two-way fixed effects model to explore the impact of digital infrastructure on agricultural total factor productivity (ATFP), and introduces a moderated mediation effect model to test the synergistic effect of resource misallocation and industrial upgrading. The results show that: (1) Digital infrastructure significantly promotes ATFP; (2) Resource misallocation plays a mediating role in this process, and it significantly inhibits ATFP; (3) With industrial structure upgrading, the promoting effect of digital infrastructure on ATFP weakens; (4) Digital infrastructure improves ATFP by suppressing resource misallocation, and industrial structure upgrading can enhance the inhibitory effect of digital infrastructure on resource distortion; (5) Spatial effect analysis reveals that digital infrastructure has a positive spatial spillover effect. Based on these findings, this paper puts forward policy suggestions such as increasing investment in digital infrastructure, balancing the relationship between industrial structure upgrading and agricultural development, strengthening policy coordination, and optimizing the regional layout and resource sharing of digital facilities to promote the positive interaction between industrial structure upgrading and digital infrastructure.

Keywords

Digital Infrastructure; Agricultural Total Factor Productivity; Resource Misallocation

1. Introduction

Agriculture is the foundational industry of national economic development[1]. Building a strong agricultural country is a major strategic task related to national economy and people's livelihood[2]. The ratio of China's ATFP to that of world agricultural powers is gradually approaching 1, indicating that China's agriculture is moving towards the direction of a strong agricultural country[3]. Composed of various physical equipment, software applications, satellite communications and network facilities[4], digital infrastructure is an important support for the efficient operation of modern economy and society[5], and the carrier of the digital economy[6]. In addition, digital technology is the core driving force for the digital economy to empower rural industrial revitalization and promote agricultural production increase[7]. The application of digital infrastructure in the agricultural field has achieved remarkable results. Digital technology empowers agricultural production, extends the industrial chain, provides impetus for the improvement of ATFP and the construction of agricultural modernization and a strong agricultural country, and its role will become more prominent in the future. Exploring its impact path has important theoretical and practical value. Based on detailed data of 281 prefecture-level cities from 2006 to 2020, this paper deeply explores the effect of digital infrastructure on ATFP.

The marginal contributions are mainly reflected in two aspects: First, from the research perspective, based on panel data of prefecture-level cities, this paper systematically examines the impact of digital infrastructure on ATFP. It not only verifies the role of digital infrastructure in promoting agricultural productivity, but also reveals its internal mechanism from the perspective of resource misallocation. Different from existing studies that mostly focus on the overall effect of the digital economy, this paper focuses on the agricultural field, providing new empirical evidence for understanding how digital technology empowers agricultural modernization. Second, from the research method, this paper innovatively constructs a moderated mediation effect model to deeply analyze the dual moderating role of industrial structure upgrading. Specifically: (1) It finds that industrial structure upgrading has a negative moderating effect on the direct effect of digital infrastructure, that is, with industrial upgrading, the promoting effect of digital infrastructure weakens; (2) It reveals that industrial structure upgrading has a positive moderating effect on the mediating path, indicating that industrial upgrading will strengthen the effect of digital infrastructure in indirectly improving productivity by improving resource misallocation. This finding breaks through the limitation of existing studies that only focus on a single moderating effect, providing a new perspective for understanding the heterogeneity of digital technology application effects.

2. Literature Review

Relevant literature mainly focuses on the impact of digital infrastructure on urban economy, agricultural development and total factor productivity, which can be divided into three categories: macroeconomic effects, roles in the agricultural field, and productivity improvement mechanisms. In terms of macroeconomic effects, some studies show that digital infrastructure can alleviate urban shrinkage[8], promote service-oriented manufacturing[9], enhance the resilience of industrial and supply chains[10], and promote inter-urban investment flows[11]; a considerable number of literatures point out that digital infrastructure is related to economic development, and its development will promote county economic resilience[12], improve the efficiency of regional innovation resource allocation[13], enhance the development level of new quality productive forces in cities[14], promote high-quality regional economic development[15], and balance regional economic development[16]. Focusing on the agricultural field, some scholars have found that digital infrastructure affects agricultural development through various channels. Based on provincial data, Liang Jian[17] conducts an empirical analysis and finds that digital infrastructure indirectly promotes the level of agricultural modernization through the diversified development of rural industries; taking 30 provinces in China as samples, Chen Jiemei and Lin Zeng[18] conduct a mechanism test, and the results show that digital construction can help modernize the agricultural industrial chain and supply chain by accelerating the integration of rural primary, secondary and tertiary industries and promoting technological innovation; Wang Zhiling et al.[19] construct a provincial agricultural economic resilience index system and find that digital technology effectively promotes agricultural industrial integration and improves the level of rural human capital, thereby enhancing agricultural economic resilience; based on prefecture-level city data, Deng Rongrong and Wu Yunfeng[20] use a difference-in-differences model and point out that narrowing the digital divide, developing digital inclusive finance, and encouraging innovation and entrepreneurship are important mechanisms for digital infrastructure construction to increase rural residents' income. Although these literatures have noticed the important role of digital facilities in promoting agricultural development, their research perspectives are mostly limited to the provincial level, lacking in-depth exploration of the impact of digital facilities on agricultural development in a wider geographical scope. In addition, some literatures deeply study how digital infrastructure specifically affects total factor productivity. Liu Bei and Huang Weidong[21] adopt a dynamic panel model and find that digital facilities help improve regional green total factor productivity; Wu Yuming and Li Ruinan[22] analyze and find that digital infrastructure construction significantly promotes the improvement of green total factor productivity in Chinese cities. Jiang Hong et al.[23], Wen Huwei et al.[24], and Guo Jinhua et al.[25] all focus on the enterprise level and find that digital infrastructure construction has a positive impact on enterprise total factor productivity. Using provincial panel data, Li Xinjue et al.[26] find that digital infrastructure significantly promotes total factor productivity; Hui Ning and Xue Ruihong[27] also study the impact of provincial digital infrastructure on total factor productivity and conclude that digital infrastructure construction improves total factor productivity. Although existing literatures have extensively discussed the relationship between digital infrastructure and total factor productivity from different dimensions, research on the impact of digital infrastructure on ATFP and its specific action paths in the agricultural field is relatively scarce.

3. Theoretical Analysis and Research Hypotheses

3.1. Digital Infrastructure and Agricultural Total Factor Productivity

The construction and improvement of digital infrastructure will have multiple impacts on ATFP, playing a crucial role in promoting agricultural modernization and improving ATFP.First, the improvement of digital infrastructure, especially the establishment of high-speed Internet, big data centers and cloud computing platforms, has greatly promoted the rapid circulation and sharing of agricultural information.Second, the application of digital technologies and new equipment has further improved the efficiency of agricultural green production[28]. With the help of digital technologies such as the Internet of Things, satellite remote sensing and unmanned aerial vehicles, prefecture-level cities can implement precision agriculture, realizing real-time monitoring of crop growth environment, precision irrigation, intelligent fertilization and early warning of diseases and pests.Finally, the improvement of digital infrastructure has promoted the close coordination of the upstream and downstream of the agricultural industrial chain, including seed supply, agricultural materials procurement, agricultural product processing, sales and logistics. Based on the above analysis, this paper proposes Hypothesis 1.

H1: Digital infrastructure promotes the growth of ATFP.

3.2. Digital Infrastructure, Resource Misallocation and Agricultural Total Factor Productivity

From the perspective of information economics, information asymmetry will cause friction and increase costs in the process of information transmission, ultimately leading to the distortion of resource allocation[29]. The improvement of factor allocation efficiency is an important source of total factor productivity growth[30]. The improvement of digital infrastructure makes the factor information mechanism in agricultural production more transparent, weakens the mobility barriers of factors in the market, and helps innovative resources flow more accurately to regions or projects with innovative potential and demand. Therefore, when the development of digital infrastructure inhibits the resource misallocation rate, it indirectly promotes the improvement of ATFP. Based on the above analysis, this paper proposes Hypothesis 2.

H2: Digital infrastructure promotes ATFP by improving resource misallocation.

3.3. Digital Infrastructure, Industrial Structure Upgrading and Agricultural Total Factor Productivity

Industrial structure upgrading is a dynamic change process of industrial structure classified by the three industries[31], a transformation of economic growth mode and economic development mode, and a result of industrial upgrading from quantitative to qualitative change. When industrial structure upgrading is combined with digital infrastructure, it may inhibit the promoting effect of digital infrastructure on ATFP. The reasons may include the following aspects: First, the difficulty of technology integration. In the process of industrial structure upgrading, the introduction of new technologies and new formats needs to be deeply integrated with the existing agricultural production system. If this integration is not smooth enough, it may limit the application effect of digital infrastructure in agricultural production, thereby inhibiting its role in improving ATFP. Second, uneven resource allocation. Industrial structure upgrading is often accompanied by the reallocation of resources. If resource allocation is not balanced enough, it may lead to the lag of digital infrastructure construction in some regions or industries, making it impossible to fully enjoy the dividends brought by digital technology, thereby affecting the improvement of ATFP.

The coordinated development of industrial structure upgrading and digital infrastructure can further promote the inhibition of resource misallocation. On the one hand, in the process of industrial structure upgrading, changes in technological progress and comparative advantages promote the optimization and adjustment of industrial structure, enabling resources to flow to more efficient and advanced industries. On the other hand, the development of digital infrastructure provides a more convenient and efficient channel for this flow, enabling the optimal allocation of resources on a larger scale. In addition, industrial structure upgrading promotes the coordinated development between industries, enabling more reasonable allocation of resources between different industries, so it can also inhibit resource misallocation itself. Industrial structure upgrading is usually accompanied by the reallocation of resources between different industries. If resource allocation is improper in this process, that is, resource misallocation occurs, agriculture may suffer losses due to resource shortage or unreasonable allocation. If agriculture cannot obtain sufficient resource support, its production efficiency will be limited, thereby affecting the improvement of ATFP, even if agriculture obtains certain resources internally, if these resources are not effectively utilized or allocated unreasonably, it will also have a negative impact on ATFP. Based on the above analysis, this paper proposes Hypotheses 3, 4 and 5.

H3: Industrial structure upgrading will inhibit the promoting effect of digital infrastructure on ATFP.

H4: Industrial structure upgrading will enhance the negative impact of digital infrastructure on resource misallocation.

H5: Industrial structure upgrading will promote the negative effect of resource misallocation on ATFP.

3.4. Spatial Effect of Digital Infrastructure on Agricultural Total Factor Productivity

In the complex pattern of regional economic development, spatial factors have always been a key dimension that cannot be ignored. All regions are not isolated. Digital infrastructure has significant public goods attributes, which determines that the development and application of digital infrastructure can hardly be limited to a single region. The information, technologies and services it carries are fluid and diffusive, enabling the optimal allocation of resources between different regions.Based on the above analysis, this paper proposes Hypothesis 6.

H6: The impact of digital infrastructure on ATFP has a significant spatial spillover effect, which can not only improve the ATFP of the region itself, but also promote the growth of ATFP in surrounding areas.

4. Research Design

4.1. Model Construction

4.1.1. Benchmark Model:

To examine the impact of digital infrastructure on ATFP at the urban level, this paper sets up a two-way fixed effects model. The benchmark econometric model is as follows:

$$atfp_{it} = \alpha + \beta base_{it} + \gamma X_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (1)$$

Where,i represents prefecture-level cities and t represents time;the explained variableatfp$_{it}$denotes the ATFP of each city; the core explanatory variable $base_{it}$ represents the level of digital infrastructure at the prefecture-level city;X_{it} represents a series of control variables;μ_i is the individual fixed effect,δ_t is the time fixed effect, and ε_{it} is the error term.

4.1.2. Mediation Effect Model:

To explore the mediating role of resource misallocation in the impact of digital infrastructure on ATFP, this paper refers to Wen Zhonglin's[32] mediation test model and sets up econometric models as shown in (2) and (3) to test Hypothesis H2.

$$capmis_{it} = \alpha_1 + \beta_1 base_{it} + \gamma_1 X_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (2)$$

$$atfp_{it} = \alpha_1 + \beta_1 base_{it} + \rho_1 capmis_{it} + \gamma_1 X_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (3)$$

Where,$capmis_{it}$ represents the resource misallocation of the i-th prefecture-level city in the t-th year; the meanings of other variables are the same as above.

4.1.3. Moderated Mediation Effect Model:

To verify Hypothesis H3, this paper constructs a regression model as shown in (4)：

$$atfp_{it} = \lambda + \rho base_{it} + \phi base_{it} * ind_{it} + \theta ind_{it} + \gamma_2 X_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (4)$$

Further,to verify Hypotheses H4 and H5, this paper introduces a moderated mediation effect model , The econometric models are as shown in (5) and (6):

$$capmis_{it} = \lambda + \rho base_{it} + \phi base_{it} * ind_{it} + \theta ind_{it} + \gamma_3 X_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (5)$$

$$atfp_{it} = \lambda + \rho base_{it} + \phi base_{it} * ind_{it} + \theta ind_{it} + \psi capmis_{it} + \pi capmis_{it} * ind_{it} + \gamma_3 X_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (6)$$

Where,ind_{it} represents the level of industrial structure upgrading of the i-th prefecture-level city in the t-th year;$base_{it} * ind_{it}$ is the interaction term between the level of digital infrastructure and the degree of industrial structure upgrading;$capmis_{it} * ind_{it}$ is the interaction term between resource misallocation and the degree of industrial structure upgrading; the meanings of other variables are the same as above.

4.1.4. Spatial Durbin Model:

To study the possible spatial spillover effect of digital infrastructure on ATFP, this paper establishes a spatial panel Durbin model as shown in (7):

$$atfp_{it} = \alpha + \rho Watfp_{it} + \beta base_{it} + \theta_1 Wbase_{it} + \gamma X_{it} + \theta_2 WX_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (7)$$

Where, ρ is the spatial autoregressive coefficient; W is the spatial weight matrix, and this paper adopts the spatial geographical distance weight matrix for spatial econometric regression;$\theta_1$represents the spatial spillover effect of the core explanatory variable digital infrastructure;$\theta_2$represents the elasticity coefficient of spatial interaction of a series of control variables.

4.2. Variable Description

4.2.1. Explained Variable：

The explained variable is the ATFP. Ordinary least squares is used to measure ATFP, which includes factor input and factor output. For factor input, referring to Xu Xuchu et al.[33], five indicators are used: land input, labor input, capital input, chemical fertilizer input and irrigation input; for factor output, referring to Yang Jun et al.[34], the total agricultural output value of each prefecture-level city. The measurement index system of ATFP is shown in Table 1.

Table 1. Measurement Index System of Agricultural Total Factor Productivity

Agricultural Total Factor Productivity	Indicators	Definitions
Factor Input	Land Input Labor Input Capital Input Chemical Fertilizer Input Irrigation Input	Total sown area of crops Number of employees in agriculture, forestry, animal husbandry and fishery Total power of agricultural machinery Chemical fertilizer application amount Effective irrigation area
Factor Output	Agricultural Output Value	Added value of the primary industry

4.2.2. Core Explanatory Variable：

The core explanatory variable is the level of digital infrastructure (base). Referring to Zhao Xing's[35] method, it is measured from two aspects: input and output, as shown in Table 2.

Table 2. Index System of Digital Infrastructure

First-level Indicators	Second-level Indicators	Calculation Methods
Digital Infrastructure Input	Optical Cable Density Per Capita Internet Broadband Access Ports Relevant Employees	Length of long-distance optical cable lines / administrative area Internet broadband access ports / total population Proportion of employees in information transmission, computer services and software industry in urban units

Digital Infrastructure Output	Telecommunication Business Income Mobile Phone Popularization Rate Internet Popularization Rate	Total telecommunication business income / total population Number of mobile phone users / total population Number of Internet broadband access users / total population

4.2.3. Mediating Variable:

The mediating variable is resource misallocation (capmis), which is measured by the degree of capital distortion in this paper. Referring to Hsieh and Klenow's[36] method, the degree of capital distortion in cities is calculated.

4.2.4. Moderating Variable:

The moderating variable in this paper is industrial structure upgrading (ind), calculated as: added value of the tertiary industry / added value of the secondary industry.

4.2.5. Control Variables:

This paper selects 7 control variables to control other factors that may affect ATFP. These variables cover dimensions such as production efficiency, ecological environment, informatization level and economic and social characteristics, which can effectively control important factors other than digital infrastructure that may affect ATFP. ① Agricultural labor productivity (labor), calculated as total agricultural output value / number of agricultural labor inputs; ② Rural greening rate (green), calculated as (rural greening area / total rural land area) × 100%; ③ Cable TV coverage rate (tv): calculated as (ratio of cable TV users to the total number of households in the region) × 100%; ④ Proportion of administrative villages with Internet broadband services (inter): calculated as (number of administrative villages with Internet broadband services / total number of administrative villages) × 100%; ⑤ Per capita net income of farmers (net): calculated as farmers' net income / total rural population; ⑥ Urban-rural income ratio (inc): its calculation formula is disposable income of urban residents / net income of rural residents; ⑦ Rural poverty incidence rate (pover): calculated as number of rural poor people / total rural population.

4.3. Data Description

This paper selects panel data of 281 prefecture-level cities in China from 2006 to 2020 for research. For some missing data, linear interpolation is used to fill in to ensure data integrity. The data are mainly from the "China Urban Statistical Yearbook", EPS database and Wind database. The descriptive statistics of variables are shown in Table 3.

Table 3. Descriptive Statistics of Variables

Variable Types	Variable Symbols	Mean	Standard Deviation
Explained Variable	atfp	1.1458	0.6482
Core Explanatory Variable	base	0.0287	0.0263

Mediating Variable	capmis	1.1404	1.0366
Moderating Variable	ind	0.9484	0.5333
Control Variables	labor	2621.36	938.73
	green	7.6832	2.8809
	tv	13.8721	5.0316
	inter	13.8736	5.0115
	net	27909.03	9949.08
	inc	2.1170	0.4381
	pover	79.9661	7.1725

5. Empirical Tests

5.1. Benchmark Regression Analysis

Based on the empirical model of the impact of digital infrastructure on ATFP, the benchmark regression results are shown in Table 4. The estimation results show that whether control variables are added or not, the coefficient of digital infrastructure is significantly positive, indicating that digital infrastructure can significantly promote ATFP, verifying H1.

Table 4. Benchmark Regression Results

Variables	atfp	
	(1)	(2)
base	3.6313*** (0.4148)	14.7088*** (0.4472)
Control Variables	Yes	No
Constant Term	-0.0048 (0.5213)	0.7243*** (0.0140)
Fixed Effects	Yes	Yes
Observations	4215	4215

Note: *, **, *** indicate significance at the 10%, 5%, and 1% levels respectively, and the values in parentheses are standard errors. The same applies to Tables 5 to 13.

5.2. Endogeneity Test

To solve the possible endogeneity problem, this paper uses population density (human) and the lagged first period of digital infrastructure (L.base) as instrumental variables for regression analysis. The results of the endogeneity test are shown in Table 5. The results show that after endogeneity treatment, the coefficients of digital infrastructure all pass the 1% significance test, confirming the accuracy of the benchmark regression test.

Table 5. Endogeneity Treatment Results

Variables	atfp	
	(1)	(2)
human	0.0009*** （0.0001）	
L.base		4.6761*** （0.4749）
Control Variables	Yes	Yes
Constant Term	-0.4746 (0.5238)	0.1238***(0.5247)

Fixed Effects	Yes	Yes
Observations	4215	3934

5.3. Robustness Test

To increase the reliability of the econometric regression results, this paper adopts four methods for robustness testing. The results of the robustness test are shown in Table 6. The results show that regardless of which robustness test is performed, the impact of digital infrastructure on ATFP is significant, proving the reliability of the benchmark regression conclusion of this paper.

Table 6. Robustness Test Results

Variables	(1) Excluding Municipalities Directly Under the Central Government	(2) Adjusting the Interval	(3) Lagged First Period of the Explained Variable	(4) Logarithmic Transformation
base	3.6900*** （0.4205）	5.0802*** （0.4408）	3.1327*** （0.3920）	
lbase				0.3937*** （0.0106）
Control Variables	Yes	Yes	Yes	Yes
Constant Term	0.1190*** (0.5245)	-0.3531 (0.4974)	-0.5066 (0.4910)	1.7659*** (0.3276)
Fixed Effects	Yes	Yes	Yes	Yes
Observations	4155	3934	3934	4215

6. Further Analysis

6.1. Mechanism Test

Mediation Effect Analysis：The results of the mediation effect test are shown in Table 7. The results in Column (1) indicate that without considering the mediating variable, digital infrastructure has a significant positive direct impact on ATFP. In Column (2), the regression coefficient of base on the mediating variable capmis is -5.3040, which passes the 1% significance test, indicating that digital infrastructure has a significant negative impact on resource misallocation. In Column (3), the regression coefficient of the variable base on atfp is sti ll significantly positive, but compared with the coefficient of atfp in Column (1), it has decreased, indicating that the mediating variable capmis plays a partial mediating role. At the same time, the regression coefficient of the mediating variable capmis on atfp also passes the 1% significance test, indicating that resource misallocation significantly inhibits ATFP, and H2 is verified.

Table 7. Mediation Effect Regression Results

Variables	Direct Effect	Mediation Effect	
	(1)atfp	(2)capmis	(3)atfp
base	3.6313*** （0.4148）	-5.3040*** （0.8938）	2.9929*** （0.4025）
capmis			-0.1199*** (0.0071)
Control Variables	Yes	Yes	Yes

Constant Term	-0.0048 (0.5213)	0.7987 (1.1246)	0.0910 (0.5036)
Fixed Effects	Yes	Yes	Yes
Observations	4215	4215	4215

Moderated Mediation Effect Analysis: Further, to identify the moderating role played by industrial structure upgrading, the regression results are shown in Table 8. In Column (1), the coefficient of base*ind is significantly negative, indicating that industrial structure upgrading plays an inhibitory moderating role in the relationship between digital infrastructure and ATFP, verifying H3. In Column (2), the coefficient of the interaction term is positive and passes the significance test. This result reveals that with the advancement of industrial structure upgrading, the inhibitory effect of digital infrastructure on resource misallocation will be enhanced, confirming H4. In Column (3), the coefficient of the interaction term capmis*ind is 0.0101, which does not pass the significance test. In the path of resource misallocation affecting ATFP, industrial structure upgrading does not play a moderating role and will not promote the negative effect of resource misallocation on ATFP, so Hypothesis 5 is not valid.

Table 8. Moderating Effect Test Results

Variables	Direct Moderating Effect	Moderated Mediation Effect	
	(1)atfp	(2)capmis	(3)atfp
base	4.6317*** （0.6588）	-17.4852*** （1.3986）	2.5186*** （0.6493）
base*ind	-0.8656** （0.4019）	9.3012*** （0.8538）	0.2479 （0.3946）
ind	0.0627*** （0.0230）	-0.2197*** （0.0488）	0.0310 （0.0228）
capmis			-0.1316*** （0.0123）
capmis*ind			0.0101 （0.0103）
Control Variables	Yes	Yes	Yes
Constant Term	-0.0666 (0.5221)	1.6494 (1.1092)	0.1324 (0.5045)
Fixed Effects	Yes	Yes	Yes
Observations	4215	4215	4215

6.2. Heterogeneity Analysis

The impact of digital infrastructure on ATFP may have significant spatial heterogeneity. This difference is mainly derived from the following mechanisms: First, according to the new economic geography theory[37] (Krugman, 1991), the diffusion effect of digital technology will be restricted by geographical location and spatial agglomeration characteristics; second, the environmental regulation theory[38] (Porter & van der Linde, 1995) shows that there are systematic differences in the efficiency of factor allocation in regions with different environmental governance levels; finally, introducing the technology suitability theory[39] (Acemoglu, 2002), the level of economic development exerts a moderating effect through the following channels: first, more complete complementary investments (such as electricity and logistics) in high-income regions reduce the cost of digital technology application; second, factor endowment misallocation in low-income regions may lead to a "technology-skill gap". Based on the above theoretical analysis, this paper constructs a heterogeneity analysis framework from three dimensions: ① Geographical location dimension: breaking through the traditional division of east, middle and west, using the Hu Huanyong Line to divide the sample into the southeast half and the northwest half to examine the impact of population density gradient on digital technology diffusion; ② Economic development level: dividing the sample into high and low groups according to the median per capita GDP to verify the threshold effect of "digital dividend"; ③ Environmental governance level: using the comprehensive utilization rate of crop straw (utilized amount / total output × 100%) as an indicator, dividing into high and low environmental governance groups based on the median to explore the moderating effect of agricultural environmental regulation intensity on the application effect of digital technology. The specific results are shown in Table 9.

Table 9. Heterogeneity Test Results

Variables	Hu Huanyong Line		Economic Development Level		Environmental Governance Level	
	(1)Southeast Side	(2)Low Per Capita GDP	(3)Low Per Capita GDP	(4)High Per Capita GDP	(5)Low Governance Level	(6)High Governance Level
base	3.5292 （2.7425）	5.8924*** （1.2956）	11.0523*** （1.6379）	1.7136 （2.5901）	0.9131 （0.5582）	8.1998*** （0.5551）
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes
Constant Term	0.5242 (0.5485)	-0.4721 (0.8967)	0.5966 (0.5238)	-0.0019 (0.6663)	0.9006 (0.7963)	-1.4675** (0.5866)
Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3808	407	2048	2167	2094	2121

The group regression divided by the Hu Huanyong Line is shown in (1) and (2). The promoting effect of digital infrastructure on ATFP is significantly stronger in the northwest region, while it does not pass the significance test in the southeast region. The group test results in Columns (3) and (4) show that in regions with low economic levels, the promoting effect of digital infrastructure on ATFP is significantly stronger, while it does not show statistical significance in regions with high economic levels. The results in Column (6) indicate that digital infrastructure significantly promotes ATFP only in cities with high environmental governance levels, with a coefficient of about 8.1998. The coefficient of base in the low governance level group is only 0.9131, and there is a significant gap in the absolute value and significance of the sample coefficients.

6.3. Spatial Spillover Effect Analysis

Spatial Correlation Test：To demonstrate whether the impact of digital infrastructure on ATFP has spatial correlation characteristics, and thus provide a theoretical basis for constructing a spatial econometric model, this paper first conducts a spatial correlation test, using the global Moran's I to analyze the spatial autocorrelation of core variables, and selecting the geographical distance matrix as the weight setting method to systematically examine the mechanism of geographical proximity on the spatial distribution of variables. The test results are shown in Table 10. It can be seen from Table 10 that the global Moran's I of ATFP and digital infrastructure are mostly in the positive interval during the research period and all pass the significance test, indicating that both have spatial autocorrelation characteristics. ATFP shows a certain agglomeration distribution in space. Although the index of digital infrastructure decreases in the later period, it also shows spatial correlation characteristics in the early period. Therefore, in exploring the impact of digital infrastructure on ATFP, the spatial effect is an important factor that cannot be ignored, and it is necessary to introduce a spatial econometric model for more in-depth analysis.

Table 10. Global Moran's I of Agricultural Total Factor Productivity and Digital Infrastructure

Year	atfp	base	Year	atfp	base
2006	0.135***	0.089***	2014	0.106***	0.088***
2007	0.130***	0.094***	2015	0.104***	0.081***
2008	0.132***	0.090***	2016	0.098***	0.070***
2009	0.128***	0.084***	2017	0.105***	0.079***
2010	0.119***	0.073***	2018	0.107***	0.072***
2011	0.123***	0.093***	2019	0.119***	0.046***
2012	0.113***	0.086***	2020	0.126***	0.031***
2013	0.106***	0.092***			

Spatial Econometric Model Diagnosis：In exploring the spatial impact mechanism of digital infrastructure on ATFP, to ensure the fit between the model setting and the actual data characteristics, it is necessary to determine the optimal spatial econometric model through a systematic test process. The results are shown in Table 11. First, the test statistics of LM-lag, LM-error, Robust LM-lag and Robust LM-error are 112.30, 171.00, 58.09 and 99.79 respectively, and the corresponding p-values are all 0.000, which are significant at the 1% significance level, indicating that the model has significant spatial lag effect and spatial error effect; second, the Hausman test statistic is 53.91, which significantly rejects the random effect hypothesis and supports the selection of the fixed effect model; finally, the test results of LR and Wald show that the spatial Durbin model cannot be reduced to the spatial lag model or the spatial error model. Based on the above test results, this paper finally adopts the spatial Durbin model with time and space double fixed effects for subsequent empirical analysis.

Table 11. Spatial Econometric Model Diagnosis Test Results

	Statistics	p-value
LM-lag	112.30	0.000
LM-error	171.00	0.000
Robust LM-lag	58.09	0.000
Robust LM-error	99.79	0.000
Hausman Test	53.91	0.000
LR_lag Test	30.75	0.000
LR_error Test	39.41	0.000
Wald_lag	28.59	0.000
Wald_error	33.51	0.000

Spatial Durbin Model Regression Results：　Table 12 shows the regression results of the spatial Durbin model of the impact of digital infrastructure on ATFP. In the regression results, the coefficient of base reaches 3.1177 in the Main part and is highly significant statistically, which clearly indicates that the improvement of local digital infrastructure can directly promote the improvement of local ATFP. At the same time, the coefficient of its spatial lag term Wx is 21.2124, which is also highly significant, meaning that the impact of digital infrastructure has a significant spatial spillover effect. That is, the development of digital infrastructure in one region not only benefits local agriculture, but also has a positive radiation effect on the ATFP of neighboring regions, promoting the coordinated development of agriculture between regions. The spatial autoregressive coefficient ρ in the model is 2.5185 and significant, which strongly verifies that ATFP has obvious spatial dependence. Agricultural development in different regions is not isolated but interrelated and mutually influential.

Table 12. Spatial Regression Results of the Impact of Digital Infrastructure on Agricultural Total Factor Productivity

Variables	Main	Wx
base	3.1177***	21.2124***
ρ	2.5185***	
σ 2	0.0486***	
Control Variables	Yes	Yes
Fixed Effects	Yes	Yes
N	4215	

The decomposition of spatial effects is shown in Table 13. The following conclusions can be drawn: ① The direct effect of digital infrastructure on ATFP is significantly positive, reaching 3.1215, indicating that at the local level, the improvement of digital infrastructure can effectively directly promote the improvement of ATFP; ② Its indirect effect is more prominent, as high as 10.3807 and highly significant, indicating that the impact of digital infrastructure has strong spatial spillover characteristics. The development of digital infrastructure in one region can significantly indirectly improve the ATFP of neighboring regions through spatial interaction; ③ The total effect is 13.5022 and significant, comprehensively reflecting the overall positive impact of digital infrastructure on ATFP, including both local effects and spatial spillover effects.

Table 13. Decomposition of the Impact of Digital Infrastructure on Agricultural Total Factor Productivity

Variables	Atfp		
	Direct Effect	Indirect Effect	Total Effect
base	3.1215***	10.3807***	13.5022***
Fixed Effects	Yes	Yes	Yes
N	4215		

7. Conclusions and Policy Suggestions

Based on panel data of 281 prefecture-level cities in China from 2006 to 2020, this paper uses a two-way fixed effects model and a moderated mediation effect model to deeply explore the relationship between digital infrastructure and ATFP, and analyzes the roles of resource misallocation and industrial upgrading. The main conclusions are as follows: (1) Digital infrastructure can significantly promote ATFP, and the conclusion remains valid after fully considering the endogeneity problem and undergoing a series of rigorous robustness tests; (2) Heterogeneity analysis shows that the impact of digital infrastructure on ATFP is more significant in the central and western regions and regions with high environmental governance levels; (3) Resource misallocation plays a mediating role in the impact of digital infrastructure on ATFP, and resource misallocation significantly inhibits ATFP. Digital infrastructure can indirectly promote the improvement of ATFP by optimizing resource misallocation; (4) In the direct effect of digital infrastructure on ATFP, industrial structure upgrading plays a moderating role, which will inhibit the promoting effect of digital infrastructure on ATFP; (5) The mediating effect of resource misallocation is affected by the moderating variable industrial structure upgrading. Industrial structure upgrading has a positive moderating mechanism on the effect of digital infrastructure on resource misallocation. When the process of industrial structure upgrading accelerates, the degree of inhibition of resource misallocation by digital infrastructure will be enhanced; (6) Spatial effect analysis finds that digital infrastructure not only directly promotes ATFP, but also has a prominent spatial spillover effect, which can drive the improvement of ATFP in surrounding areas through spatial correlation.

In this regard, this paper puts forward the following policy suggestions: (1) Increase investment in digital infrastructure construction: The government should continue to increase investment in digital infrastructure, vigorously promote the construction of the Internet, the Internet of Things and big data centers in rural areas, including expanding network coverage, improving network speed to ensure information accessibility; deploying sensors to monitor the agricultural production environment to achieve precise planting and breeding; and building big data centers to store and analyze agricultural data to provide scientific support for production decisions. (2) Balance the relationship between industrial structure upgrading and agricultural development: It is necessary to implement differentiated support policies and promote industrial integration. Specifically, we should cultivate agricultural product brands or extend the industrial chain according to regional characteristics, and promote the coordinated development of agriculture with secondary and tertiary industries such as tourism and e-commerce to prevent agriculture from being marginalized in the process of industrial upgrading. (3) Strengthen policy coordination to promote the positive interaction between industrial upgrading and digital infrastructure: We can encourage enterprises to use digital infrastructure for technological innovation and industrial upgrading through fiscal and financial measures such as tax reductions, special funds and targeted financial products; (4) Strengthen the coordination and linkage of digital infrastructure construction between regions: Give full play to its spatial spillover effect by balancing the regional layout of digital infrastructure and establishing an inter-regional data sharing mechanism to drive the overall improvement of ATFP.

References

[1] Gong Binlei, Zhang Qizheng. Paths to Promote the Construction of a Strong Agricultural Country by Improving Agricultural Total Factor Productivity [J]. Economic Perspectives, 2023, (09):29-37.

[2] Fan Shenggen, Long Wenjin, Meng Ting. Accelerate the Formation of New Quality Productive Forces to Lead the Construction of a Strong Agricultural Country [J/OL]. Journal of China Agricultural University (Social Sciences Edition), 1-15[2025-01-02].

[3] Li Zhou. The Meaning, Measurement and Approach of a Strong Agricultural Country [J]. Jiangxi Social Sciences, 2023,43(11):5-15+206+2.

[4] Lü Dan. Does Digital Infrastructure Construction Affect Corporate ESG Performance?——Empirical Analysis from the Quasi-Natural Experiment of the "Broadband China" Strategy [J/OL]. Systems Engineering-Theory & Practice, 1-19[2024-10-13].

[5] Wen Yi, Li Heshan, Zhang Lei. Digital Infrastructure, Technological Innovation and Low-Carbon Energy Consumption [J]. Economic Geography, 2024,44(09):144-152.

[6] Yang Huanhuan, Zhu Mingjiang, Chu Xianxing. Comprehensive Measurement, Spatial Evolution and Regional Difference Analysis of Digital Infrastructure Construction Level [J]. Statistics & Decision, 2024,40(17):114-119.

[7] Li Jian, Chang Qing. Digital Economy Empowers Rural Industrial Revitalization: Mechanism, International Experience and Development Path [J]. World Agriculture, 2024,(12):97-106.

[8] Tang Kai, Liu Xiaokang, Wang Haijie. Digital Infrastructure Construction and Urban Shrinkage [J/OL]. Contemporary Finance & Economics, 1-16[2025-01-15].

[9] Liu Guoliang, Fu Fan, Yang Huixin, et al. Digital Infrastructure and Service-Oriented Manufacturing [J]. On Economic Problems, 2024,(12):19-28.

[10] Zhao Chunming, Yang Hongju. Has Digital Infrastructure Construction Enhanced the Resilience of Industrial and Supply Chains?[J/OL]. Contemporary Finance & Economics, 1-15[2025-01-15].

[11] Liu Binglian, Yuan Bo, Liu Yuhai. How Does Digital Infrastructure Smooth the Flow of Capital Factors Between Regions?——Evidence from Enterprise Registration Big Data [J/OL]. The Journal of Quantitative & Technical Economics, 1-18[2025-01-15].

[12] Wang Qin, Li Jing, Ding Keke, et al. Digital Infrastructure and County Economic Resilience: A Study Based on a Quasi-Natural Experiment [J/OL]. Soft Science, 1-18[2025-01-15].

[13] Zhao Shukuan, Zhao Xukun, Shao Dong. Research on the Impact of Digital Infrastructure on the Efficiency of Regional Innovation Resource Allocation——From the Perspective of Resource Misallocation [J]. Jilin University Journal (Social Sciences Edition), 2025,65(01):148-164+238.

[14] Lu Jiang, Wang Yuping, Guo Zi'ang. The Impact of Digital Infrastructure Construction on the Development of New Quality Productive Forces [J]. Shanghai Journal of Economics, 2024,(12):16-29.

[15] Zheng Puyang, Ren Daowen, Niu Jun, et al. Digital Infrastructure Construction, Innovation Factor Allocation and High-Quality Economic Development [J]. Statistics & Decision, 2024,40(23):86-90.

[16] Xia Jiechang, Yuan Hang. The Logical Mechanism and Implementation Path of Digital Infrastructure Construction Promoting Common Prosperity [J]. Theoretical Journal, 2024,(06):123-131.

[17] Liang Jian. Digital Infrastructure, Diversified Development of Rural Industries and Chinese-Style Agricultural and Rural Modernization [J]. Statistics & Decision, 2024,40(11):40-45.

[18] Chen Jiemei, Lin Zeng. Digital Infrastructure Construction Empowers the Modernization of the Agricultural Industrial Chain and Supply Chain: Theoretical Mechanism and Empirical Evidence [J]. Journal of Yunnan University of Finance and Economics, 2024,40(04):52-68.

[19] Wang Zhiling, Zeng Hong, Luo Rong. Has Digital Infrastructure Construction Enhanced Agricultural Economic Resilience?[J]. Study & Practice, 2023,(12):33-44.

[20] Deng Rongrong, Wu Yunfeng. The Impact of Digital Infrastructure Construction on Rural Residents' Income [J]. Journal of Capital University of Economics and Business, 2023,25(01):21-35.

[21] Liu Bei, Huang Weidong. Research on the Green Total Factor Productivity Improvement Effect of New Digital Infrastructure [J]. Qiushi Journal, 2023,50(01):96-106.

[22] Wu Yuming, Li Ruinan. Can Digital Infrastructure Construction Promote the Improvement of Urban Green Total Factor Productivity?——Quasi-Natural Experiment from the "Broadband China" Pilot Policy [J]. Journal of East China University of Science and Technology (Social Science Edition), 2024,39(01):133-148.

[23] Jiang Hong, Li Silin, Yu Hongxin. The Impact of Digital Infrastructure on Enterprise Total Factor Productivity——Based on the Mediating Effect of Digital Transformation [J]. Science and Technology Management Research, 2024,44(13):92-99.

[24] Wen Huwei, Zhong Qiming. Digital Infrastructure and Enterprise Total Factor Productivity——Evidence from Chinese Listed Companies [J]. Soft Science, 2022,36(08):64-71.

[25] Guo Jinhua, Guo Mengnan, Guo Shufen. How Does Digital Infrastructure Construction Affect Enterprise Total Factor Productivity?——Quasi-Natural Experiment Based on the "Broadband China" Strategy [J]. Securities Market Herald, 2021,(06):13-23.

[26] Li Xinjue, Guan Qiuli, Li Wenjing. The Network Spillover Effect of Digital Infrastructure Promoting Productivity Growth——Dual Perspective from "Increment and Quality Improvement" [J]. Industrial Economics Research, 2023,(03):100-114.

[27] Hui Ning, Xue Ruihong. Accelerate the Construction of Digital Infrastructure and Strive to Improve Total Factor Productivity [J]. Journal of Northwest University (Philosophy and Social Sciences Edition), 2023,53(01):36-55.

[28] Regina B, Thomas D, Carl P. Who drives the digital revolution in agriculture? A review of supply-side trends, players and challenges[J]. Applied Economic Perspectives and Policy,2021,43(4):1260-1285.

[29] Goldfarb A,Tucker C.Digital economics.Journal of Economic Literature,2019,57(1):3-43.

[30] Zheng Hongyun, Li Gucheng. The Impact of Urban-Rural Policy Bias on Agricultural Resource Allocation Efficiency [J]. Journal of Agrotechnical Economics, 2020,(07):79-92.

[31] KUZNETS S. Economic growth of nations: total output and production structure [M]. Cambridge, MA: Harvard University Press, 1971.

[32] Wen Zhonglin, Zhang Lei, Hou Jietai, et al. Procedures for Testing Mediation Effects and Their Applications [J]. Acta Psychologica Sinica, 2004,(05):614-620.

[33] Xu Xuchu, Yang Wei, Wu Bin. Multiple Paths of Rural Digital Economy Empowering the Improvement of Agricultural Total Factor Productivity——Configuration Analysis Based on County-Level Data in Zhejiang Province [J]. Chinese Rural Economy, 2024,(10):84-103.

[34] Yang Jun, Sun Jiegang. Research on the Impact of Digital Economy on Agricultural Green Total Factor Productivity [J]. Dongyue Tribune, 2024,45(11):139-148.

[35] Zhao Xing. Research on the Technological Innovation Effect of New Digital Infrastructure [J]. Statistical Research, 2022,39(04):80-92.

[36] Hsieh,C.T.,and P.J.Klenow. Misallocation and Manufacturing TFP in China and India [J]. Quarterly Journal of Economics,2009,124 (4):1403-1448.

[37] KRUGMAN P. Increasing returns and economic geography[J]. Journal of Political Economy, 1991, 99(3): 483-499.

[38] PORTER M E, VAN DER LINDE C. Toward a new conception of the environ-

ment-competitiveness relationship[J]. Journal of Economic Perspectives, 1995, 9(4): 97-118.

[39] ACEMOGLU D. Directed technical change[J]. Review of Economic Studies, 2002, 69(4): 781-809.