Journal of Green Economy and Low-Carbon Development
https://www.acadlore.com/journals/JGELCD

Digital Governance in Rural China and Its Impact on Agricultural Green Total Factor Productivity

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Received: 05-02-2025 **Revised:** 06-14-2025 **Accepted:** 06-25-2025

Citation: X. Gao, "Digital governance in rural China and its impact on agricultural green total factor productivity," *J. Green Econ. Low-Carbon Dev.*, vol. 4, no. 2, pp. 116–127, 2025. https://doi.org/10.56578/jgelcd040205.

Abstract: With the application of digital technology in the political sphere, the concept of digital governance has emerged as a novel approach to governing. This study focuses on digital governance in rural China and examines its impact on agricultural green total factor productivity (AGTFP) based on the provincial-level data from 2011 to 2022. To measure digital governance in rural China, we select four sub-indexes and employ the entropy weight method. Then, the Instrumental variable two-stage least squares (IV-2SLS) method is utilized to analyze the impact of rural digital governance on AGTFP, which is assessed using the directional distance function and global Malmquist-Luenberger (GML) index. The results show that digital governance in rural China has a positive effect on AGTFP. The increase in rural digital governance by 0.1 leads to a corresponding increase of 0.0045 in AGTFP. The mechanism analysis reveals that the farmland transfer rate and the soil erosion control areas positively mediate the relationship between rural digital governance and AGTFP. Our research findings enhance the overall comprehension of rural digital governance in China and its potential for generating positive outcomes.

Keywords: Digital governance; Rural China; AGTFP; Mechanism analysis

1 Introduction

In the age of the digital economy, the way individuals lead their lives and engage in professional activities has been significantly transformed due to the ongoing advancements in digital technology such as 5G, Internet of Things (IoT), and artificial intelligence (AI). Moreover, digital technology has exerted a profound influence on national governance [1]. The extensive application of digital technology in national governance will lead to an enhancement in the quality of public services [2, 3]. Consequently, numerous countries place significant emphasis on promoting the application of digital technology in national governance and consider it as an important manifestation of digital governance.

The government of China places significant emphasis on digital governance. To comprehensively promote digital governance, it is crucial to guarantee the advancement of digital governance in rural regions. Up to now, the Chinese government proposed a series of policies. For instance, the "Digital Village Development Strategy Outline" was proposed in 2019, explaining the development direction of rural digital governance. The No. 1 central document for 2023 advocated the utilization of digital technology to enhance the capacity for rural governance. Meanwhile, due to the policy support, the significant progress has been made in the field of digital governance in rural China. For instance, the online processing rate of the six categories of rural-related government affairs (including social insurance, rural cooperative medical care, employment, rural farmland transfer, homestead management, and agricultural subsidies) was 68.2% by 2021 [4].

Digital governance in rural areas has positive effects. By installing cameras in the village, the public officials can promptly capture the incident's progression to facilitate the resolution of disputes [5]. By utilizing a mobile application for rural governance, villagers can promptly access information and contribute their own perspectives [6]. According to Zhou et al. [7], it was discovered that social well-being is enhanced through the implementation of digital governance. In addition to the above effects, digital governance in rural areas may affect the efficiency of agricultural production, because it can provide accurate and timely information, reduce information asymmetry, and thus improve the efficiency of agricultural production [8, 9]. However, the existing literature on the correlation between rural digital governance and production efficiency in agriculture is insufficient. Agricultural green total factor productivity (AGTFP) is an indicator that incorporates environmental factors into the conventional framework of total factor productivity (TFP), enabling the assessment of agricultural growth sustainability. Therefore, this study analyzes the impact of digital governance in rural China on AGTFP.

To achieve this goal, we construct a logical analysis framework and conduct empirical analysis based on the provincial panel data from China spanning from 2011 to 2022. To address the endogeneity associated with digital governance, we select the Instrumental variable two-stage least squares (IV-2SLS) method to investigate the impact of digital governance in rural China on AGTFP and its underlying mechanisms.

This study makes three contributions to the literature. First, we evaluate the extent of digital governance in rural China. In specific, we select two aspects (including digital infrastructure in rural areas and rural public management with digital features), four sub-indexes, and the entropy weight method to evaluate the extent of digital governance in rural China. The four sub-indexes include rural broadband access subscribers, mobile phone penetration, telephone penetration rate, and the total number of key terms related to rural digital governance in the policy documents issued by local governments in China. Second, we investigate the impact of digital governance in rural China on AGTFP. Logically, the implementation of digital governance in rural China has the potential to facilitate the timely and accurate transmission of various information, thereby enhancing AGTFP. In specific, digital governance in rural China could facilitate the efficient exchange of farmland transfer information between lessors and tenants, as well as expedite the accurate transmission of environmental regulation information. However, limited research has been conducted on the correlation between digital governance in rural China and AGTFP. Third, we examine the mechanism between digital governance in rural China and AGTFP from two aspects. On the one hand, rural digital governance can promote the transfer of farmlands, thereby improving AGTFP. On the other hand, digital governance in rural China can promote the enforcement of environmental regulations, thereby improving AGTFP.

The rest of this research is designed in the following manner. Section 2 introduces the literature review. The conceptual frameworks and research hypotheses are introduced in Section 3. Then, we introduce the data, variables, and descriptive statistics in Section 4. Section 5 and Section 6 show estimation strategies and empirical results, respectively. Finally, we draw conclusions and policy implications in Section 7.

2 Literature Review

2.1 Concept of Digital Governance and Its Impacts

The concept of digital governance emerged in the early 21st century, coinciding with the revolutionary advancements in Internet-based information technology. In the study of Asgarkhani [10], digital governance referred to the integration of open data and social networks into the interaction between government institutions and the public. The key characteristic of digital governance is to optimize administrative processes and improve the efficiency of governmental services through the utilization of Internet-based information technology [11]. Wong and Chu [12] showed that digital governance refers to the government's utilization of information and communication technologies with the aim of enhancing governance processes. This definition is similar to the researches [13, 14]. In addition, some scholars argued that digital governance encompasses not only the utilization of digital technology in public administration but also the effective management of the increasingly large amount of data in the whole society [15, 16]. It is worth noting that in some studies, scholars have employed the term e-governance as a substitute for digital governance [17, 18].

In the age of the digital economy, the development of digital governance (also known as e-governance) is an inevitable trend. On this basis, scholars have discussed the inherent challenges and positive impacts associated with digital governance. As for inherent challenges, Olumekor et al. [19] found that inadequate infrastructure constitutes a significant impediment to the development of digital governance in Africa. Umbach and Tkalec [20] found that the performance of digital governance is contingent upon contextual factors such as policy domain and administrative tradition. As for positive impacts, digital governance could promote governance improvement [21, 22]. In specific, digital governance has a strong and positive effect on voice, accountability, regulatory quality, and government effectiveness; however, it has a weak effect on political stability [23]. Furthermore, the economic and social impacts of digital governance have been examined by scholars, although there is a lack of empirical studies due to limited availability of data. In the limited empirical studies, Lyulyov et al. [24] found that digital governance positively impacts the attainment of Sustainable Development Goals (SDGs) in European Union countries.

2.2 Measurement of AGTFP and Its Determinants

Agricultural development is no longer confined to ensuring the basic supply and demand balance of agricultural products within resource constraints, but also takes into account environmental pollution during production. To establish a comprehensive framework encompassing agricultural production, resource allocation, and environmental factors, scholars have conducted measurements and analyses of the AGTFP. The measurement of AGTFP can be traced back to Chung et al. [25], who adopted the non-parametric method and introduced the undesirable output into the directional distance function. In specific, scholars used the directional distance function and Malmquist-Luenberger (ML) index to measure AGTFP [26]. However, ML index encounters the problem of linear programming without solutions. To solve this problem, Oh [27] provided the Global Malmquist-Luenberger (GML) index, which is transitive due to it contains a frontier shared by each phase.

The comprehension of strategies for enhancing the extent of AGTFP is significant. In previous studies, scholars have explored the influencing factors of AGTFP from multiple dimensions, including agricultural production structure, rural industrial integration, crop insurance, digital economy, environmental regulation, and social and economic development levels [28–31]. Specific to the variable of digital economy, Li et al. [31] found that the growth of China's digital economy has a notable beneficial impact on the carbon productivity of agriculture under the condition in which agricultural green technology innovation is stimulated. However, the digital economy encompasses a wide range of content, making it difficult to identify the key contents that influence agricultural green development.

3 Conceptual Frameworks and Research Hypotheses

The township governments are the grassroots administrative organs in China. According to this fact, the concept of rural digital governance in China refers to the integration of digital technology into the handling of public affairs in townships, aiming to strengthen the ties between township governments and rural residents, enterprises, and other stakeholders, while maximizing the public interest. Due to the adoption of digital technology, the township government's capacity to ensure the accuracy and timeliness of information delivery has been significantly improved. On this basis, we explain the mechanism between digital governance in rural China and AGTFP from two aspects.

First, digital governance in rural China can promote the matching of farmland transfer information between lessor and tenant, thereby improving AGTFP. On the one hand, public officials can utilize WeChat and online government service platforms to gather farmers' inclinations regarding transferring out their farmlands, as well as to make statistics on these inclinations. Then, through the Internet platform like "Land Transfer Public Service Network Platform", public officials can provide these inclinations to both local and non-local demanders. In this way, the information regarding the transfer of farmland between the lessor and lessee can be matched. On the other hand, through Remote Sensing System (RS) and Global Positioning System (GPS), public officials can obtain and provide a map depicting farmland resources for individuals and enterprises seeking to transfer in farmlands. This map facilitates an understanding of the spatial distribution of farmlands, current utilization patterns, and soil environmental conditions. Thus, individuals and enterprises who want to transfer in farmlands can find suitable farmlands as soon as possible.

Furthermore, the transfer of farmland facilitates the implementation of large-scale farmland management, thereby contributing to enhancing AGTFP [32, 33]. The main reasons can be attributed to two aspects. First, there is a higher probability for individuals and enterprises with large-scale farmland management to adopt environmentally-friendly production technologies, thereby enhancing AGTFP [33]. Second, large-scale farmland management contributes to the enhancement of agricultural mechanization, thereby leading to improved effectiveness in pesticide and fertilizer usage, as well as an increase in AGTFP [32]. For instance, drone spraying technology can significantly improve pesticide efficiency and minimize pesticide input.

Second, digital governance in rural China can promote the accurate and rapid transmission of environmental regulatory information, thereby improving AGTFP. Environmental regulation as an intervention tool is crucial for the harmonious development of the economy and resource environment, as well as ensuring the sustainability of agricultural production. The green development of agriculture is highly valued by the Chinese government, which has implemented a range of regulatory measures including the introduction of the Regulations on Pesticide Management. These regulatory measures usually have positive effects on AGTFP [33, 34], according to the theory of Porter and van der Linde [35], who proposed that environmental regulations within a reasonable range will force firms to innovate green practices.

With the development of digital governance in rural China, official information on environmental regulation is transmitted to agricultural producers in a timely and accurate manner. In addition, when environmental regulations incentivize agricultural producers to enhance their agricultural production techniques and achieve profitability, government departments can further use digital technology to quickly disseminate successful experiences and facilitate positive spillover effects. Thus, by promoting the transition of environmental regulatory information and the enforcement of environmental regulations, digital governance in rural China positively affects the AGTFP.

Taking into consideration the aforementioned explanation, we put forth the subsequent research hypotheses.

Hypothesis 1: digital governance in rural China has a positive effect on AGTFP.

Hypothesis 2: by facilitating farmland transfer, digital governance in rural China positively affects AGTFP.

Hypothesis 3: by enforcing environmental regulations, digital governance in rural China positively affects AGTFP.

4 Data, Variables, and Descriptive Statistics

4.1 Data

This research utilizes a well-balanced dataset consisting of 31 Chinese provinces, spanning from 2011 to 2022. The data pertaining to agricultural input and output variables have been obtained from the China Rural Statistical Yearbook. The data used to evaluate digital governance in rural China are derived from the policy documents issued by local governments and the China Statistical Yearbook. The data used to reflect urbanization, GDP per capita, Engel coefficient, fiscal support, natural damage rate, soil erosion control areas, and IV variable are obtained from the China Statistical Yearbook. From the China Population and Employment Statistical Yearbook, we obtain the data which can reflect education and the aging of rural population. The data used to reflect agricultural cooperatives and farmland transfer rate are sourced from the China Rural Management Statistical Annual Report. The data of average temperature and total precipitation are sourced from the China Meteorological Science Data Sharing Network.

4.2 Variables

4.2.1 AGTFP

In previous studies, the directional distance function (DDF) and global Malmquist-Luenberger (GML) index, known as the DDF-GML model, have been widely employed by scholars to quantify the AGTFP. In the DDF-GML model, the DDF can encompass both desired and undesired outputs; the GML index proposed by Oh [27] can solve the problem of linear programming without solutions encountered by the ML index. Similar to the studies [33, 36, 37], we employ the DDF-GML model to measure AGTFP. Among this model, carbon emissions are employed as a metric to quantify the undesired output [3]. We present the inputs, desired output, and undesired output variables in Table 1. Moreover, it should be emphasized that the AGTFP index derived from the DDF-GML mode represents the growth value of the latter period relative to the previous period. To guarantee the data's comparability, we establish 2011 as the base period and subsequently multiply the AGTFP index prior to that year in order to derive the cumulative AGTFP for that specific year.

Table 1. Variable definitions in the DDF-GML model and descriptive statistics

Variables		Definition	Mean (S.D.)
Input variables	Farmland	Crop sown area (10^4 ha)	534.79 (395.16)
	Labor	Agricultural employment (10^4 people)	427.53 (332.56)
	Machine	Total power of agricultural machinery (10^4 kilowatt)	3349.8 (2926.9)
	Pesticide	Pesticide usage (10^8 kg)	9.5494 (19.621)
	Agricultural film	Agricultural film usage (10^8 kg)	7.9200 (6.6726)
	Chemical fertilizer	Amount of fertilizer used in agriculture (10^8 kg)	182.81 (144.72)
	Agricultural water	Agricultural water consumption (10^8 m^3)	121.54 (105.81)
	Diesel usage	Diesel usage (10^8 kg)	65.224 (56.045)
Output variables	Desired output	Total value of agricultural output (10^8 yuan)	1924.5 (1423.1)
	Undesired output	Carbon emission (10^8 kg)	289.29 (219.46)

Note: S.D. refers to standard deviation. The input and output variables in the DDF-GML model are logarithmic.

4.2.2 Digital governance in rural China

Digital governance in rural China is the key explanatory variable. We construct the indicator of digital governance in rural China from two aspects: digital infrastructure in rural areas and rural public management with digital features. To measure digital infrastructure in rural areas, we select three sub-indexes: rural broadband access subscribers, mobile phone penetration, and telephone penetration rate. To measure rural public management with digital features, we select a single sub-index. As for the single sub-index, we identify and quantify key terms related to rural digital governance in the policy documents issued by local governments in China. That is, the measurement of rural public management with digital features is based on the total number of key terms identified in policy documents. The key terms related to rural digital governance include digital agriculture, intelligent agriculture, agricultural big data analytics, agricultural big data platforms, unmanned farming systems, autonomous agriculture practices, platform-based Internet connectivity, smart village development initiatives, e-government platforms, and cloud-based solutions for rural big data management. Then, we employ the entropy weight method to allocate weights among the four sub-indexes, followed by standardizing each sub-index.

4.2.3 Control variables

Building on previous research on AGTFP [38–40], we select the following control variables. In specific, we employ urbanization and per capita GDP as indicators to characterize the extent of economic advancement in different regions. To reflect the economic conditions prevailing in rural areas, the Engel coefficient of rural households is utilized. It is a metric to gauge the proportion of food expenditure in relation to total household expenditure. We select the intensity of financial support for agriculture and the number of agricultural cooperatives to reflect the financial and organizational support for agricultural development. In addition, the demographic characteristics of rural areas are crucial [41]; thus, we select the average years of education and aging of the rural labor force. In addition, in relation to the issue of global warming, it is necessary to acknowledge the impacts of temperature and precipitation fluctuations on agricultural productivity [42]; thus, we select the control variables of the average annual temperature, total annual precipitation, and natural damage rate.

4.2.4 Mediating variables

In accordance with our conceptual framework, we employ two mediators. The initial mediator pertains to the rate of farmland transfer (M1), which is determined by the ratio of transferred farmland area to the overall extent of farmland. The second mediator refers to environmental regulation (M2), which is measured by the soil erosion control areas.

4.3 Descriptive Statistics

The variable definitions and descriptive statistics can be found in Table 2.

Table 2. Variable definitions in empirical analysis and descriptive statistics

Variables		Definition	Mean (S.D.)
Dependent variable	AGTFP	Agricultural green total factor productivity	1.033 (0.039)
Key variable	Digital governance	The indicator is composed of four sub-indexes (rural broadband access subscribers, mobile phone penetration, telephone penetration rate, and the total number of key terms related to rural digital governance in policy documents)	0.254 (0.159)
Control variables	Urbanization	The proportion of urban population in total population (%)	60.562 (27.079)
	GDP per capita	GDP per capita (yuan [a])	10944 (5233)
	Engel coefficient	The proportion of food expenditure in total household expenditure (%)	31.129 (4.928)
	Fiscal support	The proportion of fiscal expenditure on agriculture in total fiscal expenditure (%)	11.510 (3.411)
	Agricultural cooperatives	The number of agricultural cooperatives (10^4 cooperatives)	7.146 (5.911)
	Education	The average years of education of rural labor force (years)	7.997 (1.116)
	Aging of rural population	The proportion of the aging labor force (aged 65 years or older) in the total rural labor force (aged 16 years or older) (%)	13.259 (4.183)
	Average temperature	Average annual temperature (°C)	14.007 (5.883)
	Total precipitation	Total annual precipitation (mm)	1005.2 (510.1)
	Natural damage rate	Rate of exposure to natural disasters (%)	44.264 (17.151)
Mediating variables	M1	Farmland transfer rate (%)	32.124 (16.919)
	M2	Soil erosion control areas (1,000 ha)	4084.4 (3301.2)
Instrumental variable	IV	Urban broadband access users lag one phase (10^6 households)	7.147 (5.911)
Observation			372

Note: S.D. refers to standard deviation. [a] Yuan is a Chinese currency.

In Table 2, the mean value of AGTFP is 1.033, indicating that the average annual growth rate of AGTFP during the sample period is estimated at 3.3%. The mean value of digital governance in rural China is 0.254, which significantly deviates from the theoretical maximum of 1. This discrepancy indicates the urgent need for enhanced digital governance in rural China. The average urbanization rate in China is 60.562%, suggesting that there is still potential for further advancement in China's level of urbanization. The mean values for GDP per capita and Engel coefficient are 10,944 CNY and 31.129%, respectively. On average, 11.51% of fiscal expenditure is used to support agriculture development. The mean value for agricultural cooperatives indicates the successful implementation of the idea of developing agricultural cooperatives. The averages of education and the aging of rural population highlight the imperative to enhance the human capital of China's rural labor force. The averages of temperature and total precipitation per year are 14.007℃ and 1005.2 mm, respectively. The average of natural damage rate is 44.264%, indicating that China is vulnerable to natural disasters. As for the mediating variables, the mean values of M1 and M2 are 32.124% and 4084,400 ha, respectively.

5 Estimation Strategies

5.1 Fixed-Effect Model

To test whether digital governance in rural China affects AGTFP, this research builds upon the previous study conducted by Liu et al. [43] and employs the fixed-effect model for conducting empirical analysis. The fixed-effect model can be expressed as follows:

$$\mathrm{AGTFP}_{it} = \alpha_0 + \beta_1 DGovernance_{it} + \beta_2 Z_{it} + \delta_i + \gamma_t + \mu_{it} \tag{1}$$

where, the subscript i indicates the i th province; the subscript t denotes the time period spanning from 2011 to 2022. AGTFP_{it} refers to the cumulative AGTFP that has been mentioned in Section 4.2.1. $DGovernance_{it}$ refers to the indicator of rural digital governance in China. Z_{it} refers to the control variables. δ_i and γ_t represents the province and time effect, respectively. μ_{it} is the random error term. In the end, α_0, β_1, and β_2 are the parameters to be estimated.

5.2 IV-2SLS Method

The fixed-effect model can effectively address the endogeneity problem arising from omitted variables; however, it is insufficient in resolving the endogeneity issue resulting from reciprocal causation. In this study, there is a reciprocal causation between digital governance in rural China and AGTFP. On the one hand, as discussed in Section 3 of this study, the implementation of digital governance in rural China has the potential to impact AGTFP; On the other hand, rural areas exhibiting higher levels of AGTFP may demonstrate greater openness to innovation, thereby leading to enhanced digital governance capabilities. To address the endogeneity problem resulting from reciprocal causation and ensure the accuracy of empirical results, we employ the IV-2SLS method to analyze the impact of digital governance in rural China on AGTFP. The first stage of the IV-2SLS method can be expressed as follows:

$$DGovernance_{it} = \gamma_1 IV_{i,t-1} + \gamma_2 Z_{it} + \varepsilon_{it} \tag{2}$$

where, the definitions of $DGovernance_{it}$ and Z_{it} align with those presented in Eq. (1). $IV_{i,t-1}$ refers to the instrumental variable. We measure $IV_{i,t-1}$ by the lagged one-phase variable of urban broadband access users in the ith province. The logic is that an increased number of broadband users enhances the capacity to promote digital governance in urban areas, thereby exerting a positive spillover impact on rural regions. Meanwhile, the lagged variable of urban broadband access users in the previous year does not significantly impact AGTFP in the current year. Therefore, the $IV_{i,t-1}$ employed in this study can fulfill both the criteria of correlation and exogeneity. Then, we conduct the weak identification test. The results show that the Cragg-Donald Wald F statistic is calculated to be 578.48, significantly exceeding the threshold of 16.38 , suggesting that the weak instrumental variable problem is not present.

The second stage of the IV-2SLS method can be expressed as follows:

$$\mathrm{AGTFP}_{it} = \beta^* \widehat{DGovernance}_{it} + \rho_2 Z_{it} + \varepsilon_{it} \tag{3}$$

where, the definition of AGTFP_{it} is the same as that in Eq. (1). $\widehat{DGovernance}_{it}$ refers to the predicted values from Eq. (2). Z_{it} and ε_{it} align with those presented in Eq. (2). β^* and ρ_2 are the parameters to be estimated. By performing a regression analysis on Eqs. (2) and (3), we can obtain a consistent result of β^*.

6 Empirical Results

6.1 Results of the Fixed-Effect Model

The estimated results of the Fixed-effect model are presented in Table 3. The results in Column 2 do not account for the control variables, whereas Column 3 incorporates a collection of control variables. As indicated in Column 2, the positive and statistically significant coefficient of rural digital governance implies that boosting digital governance in rural areas contributes to the enhancement of AGTFP. The results in Column 3 demonstrate a positive impact of digital governance on AGTFP at the 5% significance level. Compared to the results in Column 2, the coefficient of digital governance in Column 3 has a relatively low magnitude, suggesting that the influence of digital governance on AGTFP is overestimated if the control variables are not considered.

Table 3. Impacts of digital governance on AGTFP: Fixed-effect model estimates

Variables	AGTFP (without controls)	AGTFP (with controls)
Digital governance	0.1801 (0.0233)***	0.0728 (0.0315)**
Urbanization		0.0009 (0.0096)
GDP per capita (ln)		-0.0011 (0.0098)
Engel coefficient		0.0001 (0.0003)
Fiscal support		0.4290 (0.1130)***
Agricultural cooperatives		0.0218 (0.0138)
Education		0.0187 (0.0041)***
Aging of rural population		-0.0437 (0.1280)
Average temperature (ln)		-0.0091 (0.0061)
Total precipitation (ln)		-0.0002 (0.0051)
Natural damage rate		-0.0081 (0.0061)
Constant	0.9876 (0.0059)***	0.8430 (0.1090)***
Province effect	Yes	Yes
Time effect	Yes	Yes
Observations	372	372
Number of id	31	31
R^2	0.381	0.559

Note: Robust standard errors are shown in parentheses. ***<0.01 and **<0.05.

6.2 Results of the IV-2SLS Method

The estimates for the initial stage of the IV-2SLS method can be observed in Column 2 of Table 4, while the subsequent stage estimates are presented in Column 3. In Column 2, the significance of the positive coefficient for GDP per capita is evident, suggesting that the enhancement of regional economic development contributes to the progress of digital governance. The variable of fiscal support has a positive effect on digital governance, showing that the provision of government financial support is pivotal for the advancement of digital development. This finding aligns with the findings [44, 45], who highlighted the fact that substantial financial resources are required for the advancement of the digital economy, and these financial resources are allocated towards enhancing infrastructure and promoting digital literacy among individuals. In addition, the coefficient of IV exhibits a positive and statistically significant relationship at the 1% level, indicating that the increase in urban broadband users, as a crucial element in promoting digital governance in cities, has a beneficial spillover effect on digital governance in rural regions.

Table 4. Impacts of digital governance on AGTFP: IV-2SLS method estimates

Variables	Digital Governance	AGTFP
Digital governance		0.0455 (0.0209)**
Urbanization	0.0096 (0.0239)	-0.0010 (0.0060)
GDP per capita (ln)	0.0904 (0.0194)***	0.0233 (0.0084)***
Engel coefficient	-0.0005 (0.0007)	0.0005 (0.0004)
Fiscal support	0.9647 (0.1666)***	0.6020 (0.0730)***
Agricultural cooperatives	0.0007 (0.0164)	0.0043 (0.0079)
Education	0.0030 (0.0046)	0.0101 (0.0032)***
Aging of rural population	0.2333 (0.1532)	0.0855 (0.1710)
Average temperature (ln)	0.0253 (0.0098)	0.0031 (0.0043)
Total precipitation (ln)	-0.0001 (0.0098)	-0.0047 (0.0038)
Natural damage rate	0.0271 (0.0202)	-0.0310 (0.0152)**
IV	0.0241 (0.0015)***	
Constant	-0.9828 (0.1843)***	0.6680 (0.0890)***
Observations	372	372
Number of id	31	31
R^2	0.816	0.314

Note: Robust standard errors are shown in parentheses. ***<0.01 and **<0.05.

In Column 3 of Table 4, the key variable of digital governance has a positive and significant on AGTFP. The coefficient size of digital governance is 0.0455, meaning that a 0.1 increase in the level of digital governance is associated with a corresponding 0.0045 increase in AGTFP. The coefficient of GDP per capita is both positive and statistically significant, suggesting that the enhancement of digital governance in rural areas contributes to the augmentation of AGTFP. The coefficient of fiscal support is also positive, meaning that providing financial support to agriculture is a crucial factor in accelerating AGTFP. The significance of providing financial assistance to the agricultural sector is also evident in the researches conducted by Butler and Cornaggia [46]. The variable of education exhibits a statistically significant and positive impact on AGTFP. For agricultural producers with higher levels of education, they usually demonstrate a stronger inclination towards acquiring new knowledge and mastering novel skills, thereby exhibiting higher levels of AGTFP. The coefficient of natural damage rate is negative and statistically significant at the 1% level, meaning that the AGTFP can be diminished by unfavorable weather conditions.

6.3 Robustness Analysis

To guarantee the reliability of our findings, we utilize the equal weight method to assess the digital governance in rural China and employ the IV-2SLS method to analyze the effect of digital governance on AGTFP in rural China. The empirical results are presented in Table 5. As shown in Column 2 of Table 5, the coefficient of IV is also positive and statistically significant, showing that there is a positive relationship between IV and digital governance in rural China. Meanwhile, the coefficient of digital governance shown in Column 3 exhibits a significant and positive impact at the 5% level, indicating that the key variable of digital governance exerts a significant and positive influence. This discovery confirms the strong and favorable impact of digital governance in rural areas of China on AGTFP.

Table 5. Results of robustness tests: Substituting the key variable

Variables	Digital Governance	AGTFP
Digital governance		0.0778 (0.0347)**
Urbanization	0.0277 (0.0286)	-0.0027 (0.0055)
GDP per capita (ln)	0.1141 (0.0219)***	0.0185 (0.0091)**
Engel coefficient	0.0001 (0.0006)	0.0004 (0.0004)
Fiscal support	0.7895 (0.1996)***	0.5840 (0.0685)***
Agricultural cooperatives	-0.0407 (0.0144)	0.0075 (0.0076)
Education	0.0188 (0.0048)***	0.0087 (0.0031)***
Aging of rural population	0.0510 (0.1404)	0.0922 (0.167)
Average temperature (ln)	0.0299 (0.0081)***	0.0019 (0.0042)
Total precipitation (ln)	-0.0126 (0.0088)	-0.0037 (0.0039)
Natural damage rate	0.0368 (0.0243)	-0.0326 (0.0146)**
IV	0.0142 (0.0013)***	
Constant	-1.0420 (0.2201)***	0.7050 (0.0917)***
Observations	372	372
R^2	0.655	0.345

Note: Robust standard errors are shown in parentheses. ***<0.01 and **<0.05.

6.4 Mechanism Analysis

To deepen our understanding, we examine the nexus between digital governance in rural areas of China and AGTFP by employing the mediating variables of farmland transfer rate (M1) and the soil erosion control areas (M2). As for the mediating variable of M1, we consider the endogeneity problem and utilize the IV-2SLS model to analyze the impact of digital governance in rural areas of China on M1. In the IV-2SLS model, the utilization of IV is equivalent to that described in Eq. (2). Then, the influence of M1 on AGTFP is examined based on the Fixed-effect model. The outcomes of the second phase estimation for the IV-2SLS model are observed in Column 2 within Table 6. In Column 2, the coefficient of digital governance in rural China is both positive and significant. The outcomes of the Fixed-effect model are observed in Column 3 within Table 6. In Column 3, the coefficient of M1 demonstrates a positive and statistically significant correlation, indicating that M1 positively and significantly affects AGTFP. This finding can also be found in the study conducted by Hu et al. [47]. Therefore, M1 positively mediates the nexus between digital governance in rural areas of China and AGTFP.

Furthermore, we test the other mediating effect of M2 based on the IV-2SLS model and the Fixed-effect model. As for the impact of digital governance in rural areas of China on AGTFP, the estimation results based on the IV-2SLS model are presented in Column 2 of Table 7. As for the influence of M2 on AGTGP, the estimation results based on the Fixed-effect model are presented in Column 3 of Table 7. In Column 2, digital governance in rural areas of China positively affects M2. In Column 3, the M2 positively affects AGTFP. Therefore, M2 positively mediates the nexus between digital governance in rural areas of China and AGTFP.

Table 6. Mechanism analysis: M1 as the mediating variable

Variables	**M1**	**AGTFP**
Digital governance	22.0100 (6.3080)***	
M1		0.0007 (0.0002)***
Urbanization	1.3760 (4.4370)	0.0041 (0.0051)
GDP per capita (ln)	21.84 (3.3507)***	-0.0040 (0.0079)
Engel coefficient	0.0504 (0.1370)	0.0001 (0.0003)
Fiscal support	1.2600 (34.4000)	0.3310 (0.1000)***
Agricultural cooperatives	0.0159 (2.3620)	0.0313 (0.0070)***
Education	-0.3810 (0.9560)	0.0202 (0.0019)***
Aging of rural population	107.1 (47.4700)**	-0.0472 (0.0439)
Average temperature (ln)	1.8190 (1.4840)	-0.0069 (0.0044)
Total precipitation (ln)	-2.5510 (1.3770)*	-0.0010 (0.0040)
Natural damage rate	2.5560 (4.3410)	-0.0111 (0.0076)
Constant	-176.9 (31.13)***	0.8620 (0.0780)***
Observations	372	372
Number of id	31	31
R^2	0.510	0.561

Note: Robust standard errors are shown in parentheses. ***<0.01 and **<0.05.

Table 7. Mechanism analysis: M2 as the mediating variable

Variables	M2	AGTFP
Digital governance	2.8550 (0.6340)***	
M2		0.0176 (0.0055)***
Urbanization	-0.8570 (0.2950)***	0.0087 (0.0081)
GDP per capita (ln)	-1.8070 (0.4240)***	0.0014 (0.0097)
Engel coefficient	-0.0060 (0.0158)	0.0002 (0.0003)
Fiscal support	9.9110 (3.4360)***	0.3040 (0.1180)**
Agricultural cooperatives	1.0080 (0.2250)***	0.0415 (0.0135)***
Education	0.2090 (0.1120)*	0.0189 (0.0034)***
Aging of rural population	-2.9090 (1.8410)	-0.0299 (0.1380)
Average temperature (ln)	-0.3310 (0.1450)**	-0.0059 (0.0063)
Total precipitation (ln)	0.1070 (0.1670)	-0.0016 (0.0051)
Natural damage rate	1.4440 (0.5550)***	-0.0075 (0.0064)
Constant	20.84 (3.9270)***	0.7010 (0.1180)***
Observations	372	372
Number of id	31	31
R^2	0.419	0.561

Note: Robust standard errors are shown in parentheses. ***<0.01 and **<0.05.

7 Conclusions

Digital governance is characterized by the integration of digital technology into the existing governance system. In the age of the digital economy, the rise of digital governance signifies a dominant direction. This study focuses on digital governance in rural China and investigates its impact on AGTFP using the Chinese provincial-level data from 2011 to 2022. According to four sub-indexes (including rural broadband access subscribers, mobile phone penetration, telephone penetration rate, and the amount of rural digital governance-related key terms in the policy documents issued by governments in rural areas of China) and the entropy weight method, we assess digital governance in rural China. Meanwhile, the AGTFP is evaluated based on the DDF-GML model. Then, the impact of rural digital governance in China on AGTFP is investigated based on the IV-2SLS method. Furthermore, we investigate the mechanism that links digital governance in rural China to AGTFP.

This study draws the following conclusions. First, the assessment of digital governance in rural China reveals that the average value of digital governance in rural China is 0.254. This value deviates from the theoretical maximum of 1, indicating a pressing need for enhanced rural digital governance in China. The assessment of AGTFP reveals that the average annual growth rate of AGTFP is estimated at 3.3% during the period from 2011 to 2022. Second, the IV-2SLS model estimations indicate that digital governance in rural areas of China has a positive and significant on AGTFP. Specifically, a 0.1 increase in the extent of digital governance is associated with a corresponding 0.0045 increase in AGTFP. Third, we believe that the timeliness and accuracy of information delivery can be ensured in the context of digital technology, thereby enhancing AGTFP. Considering the information delivery of farmland transfer (measured by farmland transfer rate) and environmental regulation (soil erosion control areas), we find out that farmland transfer rate and soil erosion control areas positively mediate the relationship between digital governance and AGTFP.

The policy recommendations are made in this study. First, in order to better reduce the digital divide in China, greater emphasis should be placed on the advancement of digital governance in rural regions. To effectively improve rural digital governance in China, it is necessary to upgrade the digital infrastructure in rural areas and promote rural public administration's digitalization. Second, in the process of utilizing digital technology to administer rural regions, it is necessary for relevant governments to attach great importance to the correlation between digital governance and the high-quality development of agriculture. For instance, relative departments should utilize digital facility to visualize the geographical distribution of farmland and other pertinent information in rural areas; utilize digital platforms for accessing and disseminating agriculturally beneficial information. Third, the enhancement of AGTFP is facilitated by the improvement in farmland transfer rates and the implementation of reasonable environmental regulations. In light of this, it is imperative for relevant governments and departments to consistently promote the transfer of high-quality farmlands and implement rational environmental regulations in agriculture.

There are two limitations identified in this study that require further improvement in future research. First, due to the availability of digital governance data, we are currently unable to analyze the impact of rural digital governance on AGTFP using Chinese county-level or village-level data. By incorporating these data, we can further enhance the robustness of our research outcomes. Second, the impact of digital governance in rural areas of China on AGTFP can be mediated by various aspects, such as the provision of digital infrastructure, the facilitation of precision technology, and the dissemination of diverse information. However, limited by data availability, other mechanisms have not yet been tested. In the future, revisions are expected to be made to address these two limitations.

Data Availability

The data used to support the research findings are available from the corresponding author upon request.

Conflicts of Interest

The author declares no conflict of interest.

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