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A Study on the Mechanisms Driving the Modernization of Agriculture Through Digital Rural Development

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ABSTRACT

The Third Plenary Session of the 20th CPC Central Committee made important strategic deployments for comprehensively advancing the great cause of national rejuvenation and building a strong country through Chinese-style modernization. As a new strategic initiative, digital village construction has broadened the path for agricultural development and provided new insights for agricultural modernization. Based on an evaluation index system for agricultural modernization and digital rural development constructed from their respective definitions, and using data from 1,374 counties in China from 2014 to 2022, this study employs a two-way fixed-effects model with mediation analysis to empirically examine the mechanism through which digital rural development influences agricultural modernization. The results indicate that digital rural development significantly promotes the advancement of agricultural modernization. In terms of the mechanism of action, entrepreneurial activity and green technological innovation play mediating roles in the process by which digital rural development drives agricultural modernization; heterogeneity analysis reveals that digital rural development promotes agricultural modernization more significantly in major grain-producing regions and areas with lower levels of agricultural modernization. Based on these findings, this study proposes that the government should promote agricultural modernization through three measures: implementing differentiated regional advancement strategies, establishing a mechanism driven by mass entrepreneurship and innovation, and deepening the digital restructuring of the entire industrial chain.

KEYWORDS

Digital Rural Development; Agricultural Modernization; Entrepreneurial Activity; Green Technological Innovation

1. INTRODUCTION

The Third Plenary Session of the 20th CPC Central Committee reviewed and adopted the "Decision of the CPC Central Committee on Further Comprehensively Deepening Reform and Advancing Chinese-Style Modernization," making important strategic deployments for comprehensively advancing the great cause of national rejuvenation and building a strong nation through Chinese-style modernization. As the foundation and a vital pillar of China's national economy, agriculture is key to Chinese-style modernization. General Secretary Xi Jinping has pointed out: "To build a strong nation, we must first strengthen agriculture; only when agriculture is strong can the nation be strong. Without a strong agricultural nation, there can be no modernized nation as a whole; without the modernization of agriculture and rural areas, socialist modernization would be incomplete." The development of agricultural modernization holds significant strategic importance for China's goal of fully building a modern socialist powerhouse. At the same time, among the tasks of building a modern socialist society, the most arduous and demanding is the advancement of agricultural modernization. Since the reform and opening-up, the Communist Party of China has led the country's vast farming population

in charting a path of agricultural modernization with Chinese characteristics, achieving tremendous accomplishments. China's level of agricultural mechanization has continuously improved, agricultural infrastructure has been effectively upgraded, investment in agricultural inputs has steadily increased, and comprehensive agricultural production capacity has rapidly expanded. However, as we embark on the new journey of comprehensively building a modern socialist country and advance toward the second centenary goal in this new stage of development, the environment for China's agricultural modernization is complex and the tasks are arduous. How to address the opportunities and challenges facing China's agricultural modernization on this new journey is a topic of significant strategic importance.

Regarding the theoretical development of agricultural modernization, Tang Huajun et al. [1] (2023) argue that the characteristics of different historical periods have shaped distinct aspects of Chinese-style modernization. The first stage explored agricultural modernization from the perspective of industrial technology application [2]; the second stage placed greater emphasis on the modernization of agricultural science and technology, industry, and management [3]; the third stage elaborates on agricultural modernization from the perspectives of industrialization, commercialization, and large-scale operations [4]; the fourth stage examines agricultural modernization through the coordinated development of urban and rural areas, as well as industry and agriculture [5]; and the fifth stage sees researchers primarily exploring the theoretical implications of agricultural modernization within the context of contemporary socialist modernization [6]. Regarding the indicator system for agricultural modernization, researchers have established diverse evaluation dimensions. Some researchers have designed indicator systems based on a region's endogenous resource endowments [7]; others have adopted an efficiency-oriented approach, using agricultural inputs and outputs as basic indicators while comprehensively considering the social benefits of agricultural development, incorporating social development, the social environment [8], and sustainable agricultural development [9] to comprehensively evaluate agricultural modernization, or have considered urbanization issues beyond the efficiency perspective [10]; other researchers, based on General Secretary Xi Jinping's theoretical exposition on the three systems of agricultural modernization, have constructed evaluation dimensions for agricultural modernization from the perspectives of the modern agricultural industrial system, production system, and management system [11].

Regarding the concept of digital villages, researchers have closely linked it with digital technologies, the digital economy, and digital factors. Earlier studies on digital villages focused primarily on the promotion and application of agricultural digital technologies within the agricultural economy. When discussing the development of digital villages, the research mainly examined the degree of digitization in agriculture and rural areas and analyzed the impact of the digital economy on agricultural development. As the digital economy accelerates, expands its reach, and exerts a more profound influence, the understanding of digital villages has become more comprehensive and profound. Wang Sheng et al. [12] (2021) and Hao Aimin et al. [13] (2022) argue that the construction of digital villages is not merely about the application of digital technologies and the development of agricultural informatization. Rather, it is a process of restructuring agricultural and rural development driven by modern information technology against the backdrop of the digital economy. The scope of digital rural development encompasses not only the construction of digital infrastructure, the industrialization of rural digital sectors, and the digitization of rural industries, but also the digital integration of resource elements [12], as well as digital rural governance [14-16] and other related areas.

Regarding the impact of digital rural development on agricultural modernization, researchers have differing interpretations of the concept, leading to varied research approaches. Some researchers examine the influence of digital technology development [17-19], improvements in informatization levels [20, 21], and the intelligent transformation of agricultural production [22] on agricultural modernization. Some researchers also view the development of digital villages as a systematic project, analyzing the complex impacts of digital village development on agricultural growth from multiple

dimensions [23, 24]: Overall, there is broad consensus within the academic community that the development of the digital economy, the adoption of digital technologies, the enhancement of agricultural informatization, and the improvement of rural infrastructure significantly promote high-quality agricultural development, increase total factor productivity in agriculture, facilitate the green transformation of agriculture, foster the integration of rural industries, and advance rural revitalization.

In summary, the development of digital rural communities and agricultural modernization is a research area that has attracted significant attention in academic circles; however, there remain issues worthy of further discussion in the following aspects. First, a review of existing literature reveals that the academic community has yet to reach a definitive consensus on the theoretical implications of agricultural modernization. The connotations and denotations of agricultural modernization evolve with the times, and its evaluation indicator system is also constantly changing. The Third Plenary Session of the 20th CPC Central Committee set forth new tasks and requirements for Chinese-style agricultural modernization; therefore, based on the new requirements of the new era, it is essential to develop the theoretical connotations of agricultural modernization and construct a new system for agricultural modernization. Second, the mechanism through which digital rural development influences the advancement of agricultural modernization has not yet been clarified. Digital rural development drives the advancement of Chinese-style agricultural modernization through the growth of the digital economy, the promotion of digital technologies, and the enhancement of informatization levels; however, the specific mechanisms remain unclear. Furthermore, most existing research is conducted at the theoretical level, with limited empirical testing. More importantly, without a clear understanding of the impact mechanisms between digital rural development and agricultural modernization, it is impossible to propose scientific and constructive policy recommendations for the development of agricultural modernization in China.

2. THEORETICAL ANALYSIS AND RESEARCH HYPOTHESES

2.1. The Promoting Role of Digital Rural Development in Agricultural Modernization

Digital rural development leverages cutting-edge digital technologies to digitally transform agricultural production systems, industrial systems, and management systems, while improving farmers' living standards and promoting sustainable agricultural development at the county level. On the one hand, digital rural development propels the advancement of smart agriculture. Smart agriculture is an organizational model that integrates agricultural planning, production, operations, and management. By leveraging big data, artificial intelligence, Internet Plus, the Internet of Things, and modern communication systems, it creates a mutually supportive ecosystem linking the allocation of agricultural resources with the secondary and tertiary sectors, thereby enhancing agricultural production efficiency and quality-benefit ratios [25]. The development of digital villages has improved rural digital infrastructure, providing a practical foundation for the advancement of smart agriculture. On the other hand, digital village development has fostered a new model of green, low-carbon development. As digital village initiatives progress, an increasing number of digital information technologies are being applied to the ecological protection of key agricultural resources. By using technological means to precisely manage various agricultural production targets, these initiatives not only meet the needs of crop growth but also ensure resource conservation and prevent environmental pollution. This not only reduces environmental pollution in rural areas but also improves the quality of life for farmers. Digital technology empowers traditional agriculture, facilitates technological innovation, and integrates into production factors, thereby improving the agricultural industrial system, production system, and management system, and promoting the modernization of agriculture [26]. Based on this, this paper proposes Hypothesis 1:

H1: Digital rural development has a positive impact on the development of Chinese-style agricultural modernization.

2.2. The Mechanism Through Which Digital Rural Development Drives Chinese-Style Agricultural Modernization

Digital rural development promotes agricultural modernization by stimulating entrepreneurial activity. First, by providing digital resources such as e-commerce platforms and live-streaming platforms, digital rural development lowers the barriers to entrepreneurship and sparks farmers' entrepreneurial enthusiasm [27]; Second, the integration of digital technology with traditional finance has overcome geographical constraints and traditional financial business models, enhancing the accessibility of financial services in county-level regions and alleviating constraints on residents' access to startup capital, thereby facilitating the implementation of their entrepreneurial ideas [28]; Finally, the development of digital villages has driven the advancement of digital education in rural areas. Through distance learning and online courses, it has improved farmers' digital literacy and provided technical support for entrepreneurship [29]. The application of digital technologies has also facilitated the integration and sharing of rural information resources, providing entrepreneurs with more comprehensive and accurate market information and reducing entrepreneurial risks. Increased entrepreneurial activity has driven the transformation and upgrading of the agricultural industry, as entrepreneurs have improved agricultural production efficiency and quality by introducing new technologies, equipment, and business models. Based on this, this paper proposes Hypothesis 2:

H2: Digital rural development drives the modernization of China's agriculture by increasing entrepreneurial activity at the county level.

Digital rural development promotes agricultural modernization by driving green technological innovation at the county level. First, by establishing digital infrastructure such as agricultural IoT platforms and environmental monitoring systems, digital rural development lowers the barriers to accessing and applying green agricultural technologies, providing foundational support for the research, development, introduction, and promotion of green technologies—including water conservation, fertilizer reduction, emissions reduction, and recycling—at the county level [30]; Second, digital technology empowers financial services, optimizing the risk assessment and financing processes for green technology projects. This alleviates the financial constraints faced by county-level entities in adopting high-cost green technologies and accelerates the implementation and application of green technologies [31]; Finally, the development of digital rural communities has promoted the digital dissemination and popularization of agricultural science and technology knowledge. Through online training platforms and remote expert guidance, it has enhanced farmers' and agricultural operators' understanding and application capabilities regarding green technologies, thereby providing a talent pool to support technological innovation [32]. The deepening of green technology innovation has driven the transformation and upgrading of agricultural production methods. Through the application of new technologies such as precision agriculture, ecological circular agriculture, and smart agricultural machinery, resource utilization efficiency has been significantly improved, environmental pollution reduced, and the quality and safety of agricultural products enhanced, thereby strengthening the sustainability and competitiveness of agriculture. Based on this, this paper proposes Hypothesis 3:

H3: The development of digital rural communities promotes agricultural modernization by enhancing the level of green technology innovation at the county level.

3. RESEARCH DESIGN

3.1 Model Construction

3.1.1. Baseline Regression Model

To test the direct effect of digital rural development on agricultural modernization, this study constructs the following regression model:

$$AgrMod_{it}=\alpha_0+\alpha_1 DigVil_{it}+\alpha_2 Control_{it}+\mu_i+\nu_t+\varepsilon_{it} \quad (1)$$

Where i represents the region, t represents the year, AgrMod represents the level of agricultural modernization, DigVil represents the level of digital village development, Control is the set of control variables, μ_i is the individual fixed effect, ν_t is the time fixed effect, and ε_{it} is the random disturbance term.

3.1.2. Mediation Effect Model

To examine the mechanism through which digital rural development influences the development of Chinese-style agricultural modernization, we construct the mediation model shown in (2):

$$Mediation_{it}=\beta_0+\beta'_1 DigVil_{it}+\beta_2 Control_{it}+\mu_i+\nu_t+\varepsilon_{it} \quad (2)$$

In the equation, `Mediation` represents the mediating variables, namely entrepreneurial activity and green technological innovation. The selection of control variables `Control` and the specific interpretations of the remaining variables are consistent with those in Model (1).

3.2. Variable Selection

3.2.1. Dependent Variable

Therefore, based on an understanding of the essential characteristics of agricultural modernization, this study reviewed a vast amount of literature and statistical data. Drawing upon General Secretary Xi Jinping's important discourses, relevant documents issued by the State Council, and the research findings of scholars, and in conjunction with the current realities of China's agricultural modernization, we conclude that agricultural modernization under the framework of Chinese-style modernization should be a process supported by advanced science and technology, aimed at enhancing comprehensive production capacity, promoting farmers' income growth, and achieving sustainable agricultural development, thereby bringing about fundamental transformations in the agricultural industrial system, production system, and management system. Based on the above understanding of agricultural modernization, and adhering to the principles of completeness, systematicity, comparability, and availability in indicator selection, this study measures the level of agricultural modernization development in China's counties through four primary indicators—modernization of the agricultural industrial system, modernization of the agricultural production system, modernization of the agricultural management system, and modernization of the rural socio-economic system—and 12 secondary indicators (Table 1).

Table 1. Agricultural Modernization Evaluation Index System

Indicators	Weights	Calculation Indicators	Calculation Method	Weight	Nature
Modernization of the Industrial System	0.2383	Per capita GDP of the primary sector	Value Added of Primary Industry / Total Rural Population	0.0904	+
		Share of Agriculture, Forestry, Animal Husbandry, and Fisheries Output in Regional Gross Domestic Product	Total output value of agriculture, forestry, animal husbandry, and fisheries / Regional Gross Domestic Product	0.0587	+
		Labor productivity	Total output value of agriculture, forestry, animal husbandry, and fisheries / Total rural population	0.0893	+
Modernization of the Production System	0.3537	Grain yield per unit area	Total grain output / Total arable land area	0.0487	+
		Agricultural land productivity	Total output value of agriculture, forestry, animal husbandry, and fisheries / Total arable land area	0.0848	+
		Share of Protected Agriculture	Area of Protected Agriculture / Total Arable Land Area	0.2203	+
Modernization of the Agricultural Management System	0.3159	Average level of education per rural resident	Number of students enrolled in general secondary schools / Total rural population	0.0599	+
		Land productivity of agricultural products	Oilseed production / Total arable land area	0.1397	+
		Arable Land per Capita	Total arable land area / Total rural population	0.1163	+
Socioeconomic Modernization	0.0920	Urbanization rate	Urban Population / Total Population	0.0565	+
		Urban-rural income ratio	Urban residents' disposable income / Rural residents' disposable income	0.0313	-
		Per Capita Disposable Income of Farmers	Per Capita Disposable Income of Farmers	0.0042	+

3.2.2. Explanatory Variables

The methodology for measuring the level of digital rural development draws on the research methods of Zhang Yue et al. [33] and constructs a theoretical framework based on the eight core dimensions

of digital rural development mentioned in the "Digital Rural Development Guidelines 2.0" released by China in 2024 (rural digital infrastructure, agricultural data resources, smart agriculture, digital industries for rural prosperity, digital rural culture, digital rural governance, digital public services for rural residents, and smart and beautiful rural areas).Given that this study focuses on exploring the driving role of digital rural development in the modernization of county-level agriculture, and based on a systematic analysis of the specific construction content of each dimension as well as the measurability of corresponding indicators and the reliability of data sources, this study ultimately constructed an evaluation indicator system comprising four aspects: digital industries for rural prosperity, digital infrastructure, digital public services, and digital social life (Table 2).

Table 2. Digital Rural Development Evaluation Index System

Primary Indicators	Weight	Second-Level Indicators	Specific Indicators	Weight
Digital Prosperity Industries	0.1699	Digital Hubs	Number of Taobao Villages	0.1508
		Digital Finance	Digital Finance Digitalization Level	0.0191
Digital Infrastructure	0.6709	Mobile Phone Penetration Rate	Rural mobile device penetration rate	0.2914
		Fixed Communication Equipment Penetration Rate	Rural fixed communication equipment penetration rate	0.3795
Digital Public Services	0.0265	Digital Financial Coverage	Digital Financial Coverage	0.0164
		Physical Financial Coverage	Number of Financial Institution Branches	0.0101
Digital Social Life	0.1327	Level of online payments	Level of mobile payments in rural areas	0.0582
		Rural Innovation and Entrepreneurship Index	Rural Innovation and Entrepreneurship Index	0.0745

3.2.3. Control Variables

To mitigate estimation biases caused by omitted variables, and in line with previous research, this study includes the following control variables: First, the level of government spending (Fiscal), represented as local general budget fiscal expenditure divided by regional GDP; second, the level of regional economic development (GdpPC), represented by the logarithm of per capita GDP; third, population density (PopDen), measured as the total population at year-end per unit area; fourth, household consumption level (HouSav), represented by per capita household savings.

3.2.4. Mediating Variables

County-level entrepreneurial activity is measured using the ratio of the number of enterprises registered in the county during the current year to the total population at year-end, following the methodology of Xie Xuanli et al. (Data are sourced from China's industrial and commercial enterprise registration records. Green technology innovation is measured by the number of green patent applications filed during the current year, with data sourced from the China National Intellectual Property Administration.

3.3. Data Sources

Data are primarily sourced from the China County Statistical Yearbook, provincial statistical yearbooks, and county statistical bulletins. To enhance the researchability of agricultural modernization, this study excludes counties that have been designated as districts. Additionally, counties with a high volume of missing data were removed from the analysis. Missing data in the

remaining counties with fewer missing values were imputed using linear interpolation and mean replacement methods.

4. EMPIRICAL ANALYSIS

4.1. Direct Effect Test

Prior to conducting the regression analysis of direct effects, the results of the Hausman test indicated that a fixed-effects model should be adopted. The regression results in columns (1) to (5) of Table 3 show that, after progressively adding control variables, the positive impact of digital rural development on agricultural modernization remains statistically significant at the 1% level. In Column (5), the regression coefficient for digital rural development is 0.0274, indicating that for every one-unit increase in the digital rural index, the level of agricultural modernization increases by 0.0274 units. Overall, digital rural development promotes the development of agricultural modernization and exhibits a certain degree of robustness; Hypothesis 1 is thus validated.

Table 3. Benchmark Regression Results

	(1) AgrMod	(2) AgrMod	(3) AgrMod	(4) AgrMod	(5) AgrMod
DigVil	0.0272***	0.0272***	0.0272***	0.0274***	0.0274***
	(0.0096)	(0.0096)	(0.0095)	(0.0079)	(0.0078)
Fiscal	-	0.0003	0.0000	0.0016	0.0004
	-	(0.0038)	(0.0038)	(0.30)	(0.0036)
PopDen	-	-	-0.4227***	-0.4435***	-0.4469***
	-	-	(0.1346)	(0.0822)	(0.0824)
HouSav	-	-	-	-0.0012***	-0.0012***
	-	-	-	(0.0003)	(0.0003)
GdpPC	-	-	-	-	-0.0008
	-	-	-	-	(0.0014)
_cons	0.0819***	(0.0818)***	0.0986***	0.0986***	0.1073***
	(0.0015)	(0.0016)	(0.0050)	(0.0036)	(0.0152)
N	12366	12366	12366	12366	12366
R^2	0.1149	0.1149	0.1171	0.1184	0.1184
Individual-fixed effects	Yes	Yes	Yes	Yes	Yes
Time-fixed effects	Yes	Yes	Yes	Yes	Yes

Note: 1. ***, **, and * denote significance levels of 1%, 5%, and 10%, respectively; 2. The values in parentheses are the heteroscedastic cluster-robust standard errors of the estimated coefficients. (Unless otherwise specified, the same applies below.)

4.2. Mediation Effect Test

Based on the theoretical analysis presented earlier, this study employs a mediation model to examine the mechanisms underlying the effects of county-level entrepreneurial activity (EntAct) and green technological innovation (GrePat). Table 4Column (1) presents the baseline regression results on the impact of digital rural development on agricultural modernization in China's counties, consistent with the findings discussed earlier. Column (2) of the empirical results shows that digital rural development significantly promotes entrepreneurial activity. During the process of digital rural development, the continuous improvement of digital infrastructure—such as broadband networks and e-commerce platforms—has effectively lowered the barriers to entrepreneurship and broken down information barriers for farmers, enabling them to identify entrepreneurial opportunities more accurately. At the same time, the advancement of digital inclusive finance and online government

services helps alleviate capital constraints faced by farmers during the entrepreneurial process and simplifies approval procedures, thereby stimulating farmers' entrepreneurial enthusiasm. Entrepreneurial entities such as new-generation farmers and agricultural cooperatives have introduced modern management concepts, driving agricultural production toward large-scale and standardized development. Entrepreneurial projects such as rural e-commerce and cold-chain logistics have addressed weaknesses in the industrial chain and increased the added value of agricultural products. Entrepreneurial activities have also attracted capital and talent back to rural areas, optimized the allocation of agricultural production factors, and ultimately accelerated the process of agricultural modernization.

The empirical analysis results in Column (3) indicate that the development of digital villages can significantly promote green technological innovation at the county level. The application of IoT and big data platforms has driven the widespread diffusion of precision agriculture technologies within counties, thereby effectively reducing the cost of adopting green technologies. The demand from e-commerce platforms for certification and traceability of green agricultural products provides an incentive mechanism for technological innovation at the production end. Furthermore, the establishment of digital platforms has fostered close connections between universities, research institutions, and agricultural entities, accelerating the process of transforming green technological achievements into practical applications. The application of precision agriculture technologies can significantly reduce water and fertilizer inputs and improve resource utilization efficiency, thereby achieving a green transformation of agricultural production processes. The promotion of emission-reduction technologies effectively reduces agricultural non-point source pollution, improves the agricultural ecological environment, and provides a solid ecological foundation for the sustainable development of agriculture. Green technological innovation not only optimizes agricultural production methods but also provides technical support and economic momentum for agricultural modernization by enhancing resource utilization efficiency and the added value of agricultural products, driving county-level agriculture toward high-efficiency, green, and sustainable development.

Table 4. Mechanism Analysis Results

	(1) AgrMod	(2) EntAct	(3) GrePat
DigVil	0.0274***	0.4344***	0.4404*
	(0.0078)	(0.1180)	(0.0456)
Fiscal	0.0004	0.2789***	-0.3161***
	(0.0036)	0.0671	(0.1139)
PopDen	-0.4469***	-0.6319	-0.1295
	(0.0824)	2.1897	(2.5753)
HouSav	-0.0012***	-0.0004	0.0575***
	(0.0003)	0.0063	(0.0092)
GDP per capita	-0.0008	0.3492***	-0.1163***
	(0.0014)	0.0304	(0.0434)
_cons	0.1073***	0.3365	2.6088***
	(0.0152)	(0.3337)	(0.4755)
N	12366	12366	12366
R^2	0.1184	0.4507	0.4684
Individual-fixed effect	Yes	Yes	Yes
Time-fixed effects	Yes	Yes	Yes

4.3. Robustness Tests

To verify the reliability of the benchmark model's analysis results and ensure the accuracy of the study's conclusions, this paper conducted the following robustness tests:

Exclusion of Outliers. Given that the COVID-19 pandemic erupted in late 2019, the strict control measures it triggered significantly disrupted agricultural production and distribution in 2020 and beyond. To eliminate the interference of the pandemic's extreme exogenous shocks on the path of agricultural modernization, this study excluded the 2020–2022 observations in the robustness tests, retaining only the pre-pandemic 2014–2019 samples to more clearly identify the mechanism of action of digital rural development under normal conditions. The regression results are shown in column (1).

(2) Truncation. To avoid the influence of outliers on the regression results, this study applies truncation at the 1% level to the key explanatory and dependent variables. The regression results are shown in column (2).

(3) Inclusion of control variables. Building upon the existing control variables, we introduced urbanization level (Urban) and industrial structure (IndStr) and re-ran the regression to examine the impact on digital rural development. The results are shown in column (3). Urbanization level was measured using nighttime light data at the county level, while industrial structure was calculated as the proportion of value added from the secondary and tertiary sectors relative to regional GDP.

The regression results indicate that whether through the exclusion of outliers, truncation, or the addition of control variables, the coefficients of the core explanatory variables remain significant and show little change compared to the baseline regression results, demonstrating the robustness of the analysis.

Table 5. Robustness Test Results

	(1) Removal of Outliers	(2) 1% Truncation	(3) Inclusion of Control Variables
	AgrMod	AgrMod	AgrMod
DigVil	0.0249**	0.0219***	0.0294***
	(0.0107)	(0.0082)	(0.0095)
Fiscal	-0.0011	0.0014	0.0011
	(0.0055)	(0.0033)	(0.0042)
PopDen	-0.2323*	-0.4490***	-0.4105***
	(0.1210)	(0.1372)	(0.1247)
HouSav	-0.0048***	-0.0017***	-0.0009**
	(0.0009)	(0.0004)	0.0005)
GDP per capita	0.0032	-0.0016	-0.0014
	(0.0030)	(0.0017)	(-0.0025)
Urban	-	-	-0.0007***
	-	-	(0.0002)
IndStr	-	-	0.0009
	-	-	(0.0008)
_cons	0.0673**	0.1152***	0.1126
	(0.0333)	(0.0189)	0.0265
N	8244	12366	12366
R^2	0.1470	0.1824	0.1223
Individual-fixed effects	Yes	Yes	Yes
Time-fixed effects	Yes	Yes	Yes

4.4. Heterogeneity Analysis

(1) Heterogeneity of Grain Production Functional Zones

Food is the foundation of human survival. A thorough examination of the differentiated impacts of digital rural development on the sustainable agricultural development of various grain production functional zones is of great significance for regions to formulate targeted policies, maximize their comparative advantages, and accelerate the pace of sustainable agricultural development. In light of this, the research sample is categorized into two major groups—major grain-producing regions and non-major grain-producing regions—based on whether the respective provinces are major grain-producing provinces, and the study systematically analyzes the differing impacts of digital rural development in these two types of regions. As can be seen from columns (1) and (2) of Table 6, the promotional effect of digital rural development is more pronounced in major grain-producing regions. Advancing digital rural development in these regions plays a crucial role in further enhancing grain production efficiency and quality, as well as stabilizing national grain supply and market prices.

(2) Heterogeneity in the Level of Agricultural Modernization

This paper classifies regions into two categories—high and low levels of agricultural modernization—based on the mean agricultural modernization score to examine the heterogeneity of the impact of digital rural development. The results in columns (3) and (4) of Table 6 show that in regions with high levels of agricultural modernization, the promotional effect of digital rural development on agricultural modernization is greater than in regions with low levels; however, the promotional effect in low-level regions is more pronounced compared to high-level regions.In regions with a high level of agricultural modernization, agricultural production has already established a certain foundation of modernization and intelligence. These regions typically possess relatively well-developed agricultural infrastructure, advanced agricultural technologies, and a highly skilled farming population. This provides a solid foundation for the advancement of digital rural development, enabling the application of digital technologies in agricultural production to be smoother and more efficient, thereby further driving the development of agricultural modernization. In regions with a low level of agricultural modernization, challenges such as weak infrastructure, outdated technology, information isolation, low production efficiency, and a shortage of talent are commonly encountered. A low level of agricultural modernization implies significant room for efficiency improvement and the presence of development bottlenecks, making the introduction of digital technologies capable of bringing about disruptive changes and enabling leapfrog development. Consequently, the promotional effects of digital technologies are more pronounced in relative terms in these regions.

Table 6. Heterogeneity Test Results

	(1) Major grain-producing regions	(2) Non-major grain-producing regions	(3) High Level	(4) Low Level
	AgrMod	AgrMod	AgrMod	AgrMod
DigVil	0.0404***	0.0084	0.0326**	0.0159***
	(0.0144)	(0.0105)	(0.0150)	(0.0043)
Fiscal	-0.0022	0.0029	-0.0043	0.0019
	0.0089	(0.0039)	(0.0078)	(0.0020)
PopDen	-0.4185***	-0.5587***	-0.4373***	-0.2421***
	0.1475	(0.2106)	(0.1568)	(0.0648)
HouSav	-0.0018**	0.0005	-0.0007	-0.0021***
	0.0008	(0.0006)	(0.0005)	(0.0003)
GDP per capita	-0.0053*	-0.0029	0.0034	-0.0022*
	0.0031	(0.0030)	(0.0030)	(0.0016)
_cons	0.1596	0.1206***	0.0925*	0.1010***
	(0.0358)	(0.0320)	(0.0472)	(0.0126)
N	7263	5103	5233	7133
R^2	0.1485	0.1012	0.0459	0.2846
Individual-fixed effects	Yes	Yes	Yes	Yes
Time-fixed effects	Yes	Yes	Yes	Yes

5. SUMMARY AND RECOMMENDATIONS

5.1. Summary

Based on panel data from 1,374 counties nationwide covering the period from 2014 to 2022, this paper examines the driving role of digital rural development in agricultural modernization and its underlying mechanisms. The results indicate that the development of digital villages significantly promotes agricultural modernization. Specifically, entrepreneurial activity and green technological innovation play important mediating roles in this process, suggesting that the development of digital villages drives agricultural modernization by enhancing farmers' entrepreneurial activity and improving the level of green technological innovation. Furthermore, heterogeneity analysis reveals that the promotional effect of digital village development on agricultural modernization is more pronounced in major grain-producing regions and areas with lower levels of agricultural modernization.

5.2. Recommendations

5.2.1. Implement a Differentiated Regional Promotion Strategy

Regions with weak agricultural modernization face prominent challenges such as insufficient digital infrastructure, low levels of agricultural technology adoption, low digital literacy among farmers, and a lack of industrial scale. These areas represent key entry points for digital villages to empower agricultural modernization and should be prioritized for policy support. In response, top-level design and financial safeguards should be strengthened. Investment in digital infrastructure—such as the Agricultural Internet of Things ( ), satellite remote sensing monitoring, and 5G gigabit optical networks—should be increased to bridge the "last mile" of digital information access to households. This will help build an integrated "air-ground-space" monitoring network and solidify the technological foundation for agricultural modernization. At the same time, targeted policy support should be introduced to expand the coverage of subsidies for purchasing smart agricultural machinery

and optimize the criteria, with a focus on Beidou-navigated machinery and smart irrigation equipment to reduce the cost of digital transformation. A digital skills training system combining online and offline approaches should be established, offering training in smart farming, agricultural machinery operation, and data interpretation tailored to regional leading industries. This will cultivate local digital agriculture technical experts, simultaneously enhancing agricultural production efficiency and farmers' digital literacy, and steadily advancing agricultural modernization.

5.2.2. Building a "Mass Entrepreneurship and Innovation" Driven Mechanism

In terms of fostering an entrepreneurial ecosystem, efforts will focus on county-level digital agriculture to build a full-chain entrepreneurial service system. A dedicated incubation fund will be established to support new business models such as smart farms, agricultural e-commerce, and digital agricultural services, providing one-stop support for returning and local entrepreneurs to reduce startup costs and risks. An entrepreneurial incubation platform will be built to integrate industrial chain resources, promote multi-party collaboration, cultivate high-quality digital agriculture startup projects, attract various talents to return to or settle in rural areas, and stimulate rural innovation and entrepreneurship.

In terms of green technological innovation, we will establish collaborative innovation platforms between research institutions and county-level entities to promote the localization and adoption of green digital technologies. Relying on universities and research institutes, we will conduct R&D on water-saving irrigation, precision fertilization, and green pest control, optimizing solutions based on actual production conditions. Improve policy incentives by using subsidies and tax breaks to encourage stakeholders to increase investment, thereby closing the loop between technological innovation, technology transfer, and industrial application. This will enhance the level of green and precision agriculture, promote high-quality and sustainable agricultural modernization, and support the modernization of agricultural product distribution as well as the process of Chinese-style agricultural modernization.

5.2.3. Deepening the Digital Transformation of the Entire Agricultural Industry Chain

On the production side, promote the deep integration of digital technology with agricultural production. Popularize digital systems such as smart monitoring and disaster early warning, build an integrated monitoring network, and promote models such as smart seeding, precision fertilization, and drone-based plant protection to enhance the precision and intelligence of agricultural production. On the distribution side, we will establish digital platforms for connecting production and sales, set up county-level e-commerce distribution centers for agricultural products, utilize big data to achieve precise matching between production and sales, and promote digital monitoring of cold-chain logistics and blockchain-based traceability to reduce losses and enhance product quality and market competitiveness. On the service side, integrate resources such as agricultural technology, credit, insurance, and information to build a one-stop digital agricultural service platform. Innovate digital credit and insurance products, provide online agricultural technical guidance, resolve financing challenges, and enhance the technological content and resilience of the agricultural industry.

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REFERENCES

[1] Tang Huajun, Wu Yongchang, Chen Xueyuan. Chinese-Style Agricultural and Rural Modernization: Evolutionary Characteristics, Challenges, and Policy Recommendations [J]. Issues in Agricultural Economics, 2023, (04): 4-13.

[2] Cao Junjie. The Evolution of Theories, Policies, and Practices of Agricultural Modernization Over the 70 Years Since the Founding of New China [J]. Journal of Zhongzhou, 2019, (07): 38-45.

[3] Kong Xiangzhi, Xie Dongdong. Chinese-Style Agricultural Modernization: Exploration Process, Basic Connotations, and Implementation Pathways [J]. Journal of Zhejiang University of Business and Technology, 2023, (02): 82-91.

[4] Qin Cheng, Wang Bao, Chen Dian, et al. Evaluation of the Development Level of Agricultural and Rural Modernization by Region in China [J]. Chinese Journal of Agricultural Resources and Regional Planning, 2022, 43 (04): 173-182.

[5] Gong Qinlin, Zou Donghan. Research on the Measurement and Improvement of the Coupling and Coordination Levels Among Industry, Agriculture, and Urban-Rural Areas in the Context of Rural Revitalization [J]. Soft Science, 2020, 34(06): 39-45.

[6] Li Mingxing, Qin Yue. Modernization of Agriculture and Rural Areas: Historical Retrospective, Contemporary Implications, Objectives, and Implementation Pathways [J]. Contemporary Economic Research, 2022, (11): 71-82.

[7] Zhong Funing. Historical Evolution of China's Agricultural Management System from the Perspective of Factor Allocation [J]. Chinese Rural Economy, 2021, (06): 2-14.

[8] Chang Yanhua, Zhang Hongli, Shi Bo, et al. Dynamic Evolution and Trend Forecast of China's Agricultural Modernization Level [J]. Economic Issues, 2022, (05): 82-89.

[9] Long Dongping, Li Tongsheng, Miao Yuanyuan, et al. Spatial Differentiation and Types of China's Agricultural Modernization Development Level [J]. Acta Geographica Sinica, 2014, 69(02): 213-226.

[10] Xin Ling, Wang Jimin. Evaluation of the Level of Agricultural Modernization in China's Counties: An Empirical Analysis Based on 1,980 Counties Nationwide [J]. Research on Agricultural Modernization, 2014, 35(06): 673-678.

[11] Zhang Junjie. Spatio-temporal Characteristics and Analysis of Obstacles to the Development of Agricultural and Rural Modernization in China [J]. Economic System Reform, 2022, (02): 87-94.

[12] Wang Sheng, Wu Dabing. The Communist Party of China's Centennial Exploration, Experience, and Outlook on "Agriculture, Rural Areas, and Farmers" Issues [J]. Rural Economy, 2021, (07): 1-10.

[13] Hao Aimin, Tan Jiayin. Mechanisms and Effect Measurement of Rural Industrial Integration in Empowering Agricultural Resilience [J]. Agricultural Technology Economics, 2023, (07): 88-107.

[14] Yin Haodong, Huo Peng, Wang Sangui. Digital Transformation of Agriculture and Rural Areas: Current Characteristics, Impact Mechanisms, and Promotion Strategies [J]. Reform, 2020, (12): 48-56.

[15] Shen Feiwei. Endogenous Development Models of Digital Villages: Practical Logic, Operational Mechanisms, and Optimization Strategies [J]. E-Government, 2021, (10): 57-67.

[16] Luo Qianfeng, Zhao Qifeng, Zhang Liyang. Theoretical Framework, Efficiency-Enhancing Mechanisms, and Implementation Pathways for Digital Technology to Empower High-Quality Agricultural Development [J]. Contemporary Economic Management, 2022, 44(07): 49-56.

[17] Mao Yufei, Li Ye. The Internet and Human Capital: A New Engine for Modern Agricultural Economic Growth — An Empirical Study Based on China's Interprovincial Panel Data [J]. Rural Economy, 2016, (06): 113-118.

[18] Lian Junhua. Digital Finance Development, Rural Inclusive Finance, and Agricultural Economic Growth: Empirical Evidence from Chinese County-Level Data [J]. China Soft Science, 2022, (05): 134-146.

[19] Li Qiannan, Li Gucheng. The Impact of Internet Development on the Growth of Total Factor Productivity in Agriculture [J]. Journal of Huazhong Agricultural University (Social Sciences Edition), 2020, (04): 71-78+177.

[20] Lin Haiying, Li Wenlong, Zhao Yuanfeng. A Study on the Relationship Between Agricultural Informatization Levels and Agricultural Economic Growth from the Perspective of Agricultural Technological Innovation [J]. Research on Science Management, 2018, 36(02): 80-83.

[21] Zhu Qiubo, Bai Junfei, Peng Chao, et al. Has Informatization Enhanced Agricultural Productivity? [J]. Chinese Rural Economy, 2019, (04): 22-40.

[22] PHASINAM K, KASSANUK T, SHABAZ M. Applicability of the Internet of Things in Smart Farming [J]. Journal of Food Quality, 2022, (02): 7696922

[23] Wang Fei, Sun Shuhui, Liu Tianjun. Has the Development of the Digital Economy Driven the Transformation of Agricultural Production Methods? Evidence from Prefecture-Level Cities in the Yellow River Basin [J]. Chinese Rural Economy, 2023, (09): 122-143.

[24] Lei Zequ, Qi Chunjie, Wang Liukun. Can Digital Rural Development Drive High-Quality Growth in the Agricultural Economy? [J]. Journal of Huazhong Agricultural University (Social Sciences Edition), 2023, (03): 54-66.

[25] Tang Huimin. Theoretical Interpretation and Practical Development of Digital Technology Empowering Rural Revitalization [J]. Rural Economy, 2022, (09): 42-51

[26] Li Ming. A Study on Pathways for "Digital Villages" to Empower High-Quality Agricultural Development [J]. Agricultural Economics, 2023, (10): 36-37

[27] Tian Zhe, Lei Lin. The Impact of Digital Rural Development on Common Prosperity for Farmhouseholds: Based on the Mediating Role of Returning Migrant Workers' Entrepreneurship [J]. Technology and Economy, 2024, 43(05): 22-31

[28] Song Donglin, Tian Guanghui, Xu Yingdong. Does Digital Finance Reduce Income Inequality?—A Study on the Income and Employment Effects of Entrepreneurship [J]. Journal of Lanzhou University (Social Sciences Edition), 2022, 50(03): 38-51

[29] Beaman L, Benyishay A, Magruder J, et al. Can Network Theory-Based Targeting Increase Technology Adoption? [J]. American Economic Review, 2021(6): 1918-43

[30] Zhu Honggen, Zhou Bofan. Digital Rural Development and Green Agriculture: Theory and Empirical Evidence [J]. World Agriculture, 2025, (03): 42-54

[31] Ding Sajie, Chen Guojin, Zhao Xiangqin, et al. Digital Technology Empowerment and the High-Quality Development of China's Green Finance [J]. International Finance Research, 2025, (11): 3-14

[32] Satpathy B. Digital Transformation for Sustainable Agriculture: A Progressive Method for Smallholder Farmers. Current Science in India, 2022; 123(12): 1436-1440

[33] Zhang Yue, Zhang Bo, Zhou Yingheng. The Impact of Digital Rural Development on Farmers' Income: A Perspective Based on Income Levels and Income Structure [J]. Journal of Agricultural and Forestry Economics and Management, 2023, 22(03): 350-358.

[34] Xie Xuanli, Shen Yan, Zhang Haoxing, et al. Can Digital Finance Promote Entrepreneurship?—Evidence from China [J]. Economics (Quarterly), 2018, 17(04): 1557-1580