

Research on Digital Economy Enabling China's Agricultural Rural Modernization

--Based on empirical tests of mediated effects models

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ABSTRACT

In the context of the rapid development of digital economy, its correlation with agricultural modernization and rural development has become increasingly prominent. This paper adopts a two-way fixed-effects model combined with a mediated-effects model to systematically examine the impact of digital economy on the process of agricultural and rural modernization and its transmission paths based on the panel data of 31 provincial-level administrative regions in China from 2011 to 2023. The empirical results show that the development of digital economy has a significant role in promoting the modernization of agriculture and rural areas, and that the digital economy can indirectly promote the modernization of agriculture and rural areas through the drive of scientific and technological innovation and the optimization of human resources.

KEYWORDS

Agricultural and rural modernization; Digital economy; Innovation-driven; Human resources

1. INTRODUCTION

The party's twentieth session of the Third Plenary Session of the Party Central Committee in the new situation around the "three rural" work of a series of major decisions and deployments for the modernization of agriculture and rural development of a clear direction. The Party's "14th Five-Year Plan" proposes to realize the modernization of agriculture and rural areas by 2025, which not only marks China's progress towards agricultural modernization, but also a major change in the upgrading of technological equipment and restructuring of the industrial system. 2025 Central Committee's "No.1 Document" states that, through the comprehensive revitalization of the countryside and the construction of a strong agricultural country, the reform, opening-up and scientific and technological innovation as the driving force, constituting the modernization of agriculture and rural areas. Reform, opening-up and scientific and technological innovation as the driving force, constituting the core path of high-quality development of agricultural and rural modernization. As a new quality production factor, the digital economy centered on information technology and data is deeply integrated with agriculture and rural areas, which can not only enhance the total factor productivity of agriculture, but also accelerate the two-way flow of resources between urban and rural areas, and become the core kinetic energy to promote the implementation of the strategy of revitalization of the countryside. The Outline of Digital Rural Development Strategy proposes to systematically promote the modernization process of agriculture and rural areas by constructing an inclusive development mechanism driven by digital technology, and giving priority to agriculture and rural areas in the allocation of technical resources, policy support system and infrastructure construction. It can be seen that the digital economy, by virtue of its empowering effect, breaks the shackles of traditional agriculture in resource

allocation and information circulation, integrates the industrial chain, drives production, injects vitality into agricultural and rural development, and accelerates the transformation of agricultural and rural modernization.

Domestic scholars' research on the modernization of agriculture and rural areas mainly focuses on three key levels, namely, enabling mechanism, innovation mode, and application scenarios. In terms of the enabling mechanism of agricultural production, the application of digital technology has become the core point, exploring the practical path of Internet of Things, big data and other technologies in precision agriculture, intelligent equipment and other aspects. Regarding the model innovation of digital economy-driven agricultural industry upgrading, it focuses on the digital reconstruction of the agricultural industry chain[2], the integrated development of the three industries, and the cultivation of new business forms, such as agricultural product e-commerce[3] and so on. The application of digital governance system in rural revitalization has a wide range of application scenarios, covering such institutional innovation fields as smart agriculture[4] and rural collective asset digitalization reform[5]. Existing research has provided strong support for the positive role of the digital economy at the technical level, and has achieved remarkable results in enhancing the total factor productivity of agriculture and promoting the two-way flow of resources between urban and rural areas, which effectively contributes to the realization of high-quality agricultural and rural development.

Based on existing research, most of the current discussions on digital economy-enabled agricultural rural modernization and development are limited to single-dimensional profiling. The overall research combining theoretical modeling and multidimensional empirical analysis is still blank. In view of this, this paper focuses on the impact mechanism of digital economy on agricultural rural modernization, and intends to carry out an in-depth investigation from multiple dimensions. First, a solid theoretical framework is laid for the study by constructing the evaluation index system of agricultural and rural modernization and the mediation effect model. Second, panel data from 31 provinces, municipalities and autonomous regions (excluding Hong Kong, Macao and Taiwan) in China from 2011 to 2023 are used to conduct rigorous empirical analysis. Under the research paradigm of combining theory and empirical evidence, we comprehensively analyze the role of digital economy in promoting the modernization of agriculture and rural areas, aiming to provide scientific and reliable theoretical basis and data support for relevant policy formulation and practical development.

2. THEORETICAL ANALYSIS AND RESEARCH HYPOTHESIS

2.1. Direct Enabling Mechanisms of the Digital Economy for Agricultural and Rural Modernization

(1) Production efficiency change. Digital technology to promote the transformation of agricultural production efficiency is the key technical support for the realization of agricultural and rural modernization[6]. On the one hand, digital technology plays an important role in promoting the intelligent transformation of agriculture, relying on the Internet of Things to build a sensing network can be a full-cycle dynamic monitoring of farmland ecological environmental parameters, and its generation of multi-dimensional agricultural data sets for the construction of precision agricultural decision support system provides a key technical support. On the other hand, due to the in-depth application of agricultural big data analysis technology to build an intelligent decision support framework based on data science, the unit production cost can be significantly reduced by optimizing the allocation of production factors, and the quality of agricultural products can be simultaneously improved at the same time, relying on the digital transformation of the entire production chain, to achieve a systematic leap in the competitiveness of the agricultural industry. The popularization of digital technology is prompting agricultural production from the past rough mode to rapidly shift to

intelligence and precision, through the extensive application of digital tools, in order to enhance the efficiency of agricultural production at the same time also makes the allocation of resources more reasonable, and promotes the transformation and upgrading of modern agriculture.

(2) Industrial structure upgrading. The digital economy promotes the integrated development of rural primary, secondary and tertiary industries by optimizing the rural industrial structure[7]. On the one hand, the rise of e-commerce platforms has opened a broader outlet for agricultural products, shortened the circulation chain, reduced transaction costs, and helped farmers realize increased income. Through online channels, agricultural products can be directly connected to consumers, reducing the middleman link in the traditional sales model, which not only improves profit margins, but also allows farmers to gain more income. On the other hand, digital technology has also given rise to new rural business forms, such as digital agriculture, rural e-commerce live broadcasting, smart rural tourism, etc., further expanding the development space of rural industry. Nowadays, e-commerce live broadcast has become a bridge connecting consumers and agricultural products, reshaping the sales model of traditional agriculture; there are also national experimental zones for comprehensive agricultural reform through the organization of e-commerce live broadcasting contest, promoting agricultural products out of the geographical limitations, to face the national and even the global consumers, and so on. In addition, digital technology has also promoted the integrated development of rural culture and tourism and other industries, giving rise to a series of new industries such as farming experience, tourism agriculture, rural lodging, etc. These new development modes not only increase the value of rural industries, but also open up more non-agricultural employment channels for farmers, and to a certain extent promote the diversification of the rural economy. Based on the above analysis, this paper puts forward the research hypothesis.

H1: The digital economy can directly contribute to Chinese-style agricultural and rural modernization

2.2. Indirect Enabling Pathways for Digital Economy-Enabled Agricultural and Rural Modernization

(1) Innovation-driven empowerment. The digital economy has stimulated the vitality of agricultural science and technology innovation, realizing the intelligent management and precise operation of the whole chain of agricultural production through the extensive integration and application of big data, artificial intelligence, the Internet of Things and other technologies in the agricultural production chain[8]. The new agricultural production management not only significantly reduces the production expenditure, but also significantly improves the output and quality of agricultural products, prompting the agricultural development model from relying on resource inputs to a new stage with innovation as the core driving force, thus indirectly promoting the modernization of rural agriculture. From the perspective of factor allocation, digital technology optimizes the allocation efficiency of agricultural information factors, effectively bridges the information gap and reduces the barriers to knowledge acquisition, and drives the R&D iteration rate and diffusion intensity of the agricultural technology innovation chain, building a complete transformation channel of "basic research - technology development - industrial application" and forming a new development paradigm of precise coupling of technological supply and production demand. In other words, through digital means, agricultural science and technology and production practice have achieved closer integration, promoting agriculture to the modernization and intelligent direction. Based on the above analysis, this paper proposes research hypotheses.

H2: Digital economy empowers Chinese-style agricultural and rural modernization through innovation drive

(2) Human resource empowerment. With the wide application of digital technology in rural areas, the demand for digital talents in rural areas is increasing[9]. On the one hand, the rise of digital economy not only opens up new development space for rural areas, but also attracts a large number of high-quality talents to return to rural areas, injecting new vitality into rural economic development[10].

The return of these talents not only brings advanced technology and management experience, but also provides intellectual support for rural economic development and enriches the rural talent pool, thus accelerating the digital transformation of the rural economy and injecting new vitality and innovation power into the countryside. On the other hand, the development of the digital economy also provides convenient learning opportunities for rural laborers, significantly improving their digital skills and comprehensive quality. Through digital education platforms and online training courses, farmers are able to acquire knowledge and skills more efficiently, and rural laborers are able to improve their digital skills and comprehensive quality, thus better adapting to the development needs of the digital economy era. Based on the above analysis, this paper puts forward the research hypothesis.

H3: Digital economy empowers Chinese-style agricultural and rural modernization through human resources

3. RESEARCH DESIGN

3.1. Variable Selection

(1) Explained variable: level of agricultural and rural modernization (y). Combined with the research results of Li Yuan et al. (2023), this paper selects eight basic indicators from four aspects, namely industry, production, life and governance, to construct a comprehensive evaluation index system of agricultural and rural modernization, and the specific index system is shown in Table 1.

(2) Explanatory variables: digital economy development index (x). Referring to the research of Yu Tonghui et al. (2023)[11], combined with the availability and comparability of data, six basic indicators are selected to construct a comprehensive evaluation index system of digital economy, and the specific index system is shown in Table 2.

Table 1. China's agricultural and rural modernization indicator system

Level 1 indicators	Secondary indicators	Variable selection	Description of calculations
government field official (old) deed government field official (old) village appear (geological) eon ... -ize	modernization of industry, one of Deng Xiaoping's Four Modernizations	Food output rate	Grain yield per unit area (kg/ha)
		Level of agricultural output	Gross agricultural product (million dollars)
	modernization of production	Percentage of effective irrigated area	Effective irrigated area/total sown area of crops
		Intensity of pesticide use	Pesticide use/area sown to crops
	modernize one's life	Engel's coefficient	Consumption expenditure on food/consumption expenditure per rural inhabitant
		Level of farmers' income	Per capita disposable income of rural households
	modernization of governance, one of Deng Xiaoping's Four Modernizations	Level of democratic rural self-government	Number of village committees/total rural population
		Level of governance in rural communities	Expenditures on urban and rural community affairs in local finance

Table 2. Digital economy indicator system

Level 1 indicators	Secondary indicators	Meaning of the indicator	Description of indicators
Level of development of the digital economy	Digital infrastructure	Internet broadband access rate	Number of Internet broadband access ports/total population
		Scale of mobile communication facilities	Mobile telephone exchange capacity
	Degree of digital application	Internet penetration	Number of Internet users/total population
		Cell phone penetration rate	Number of cell phone subscribers/total population
	Digital Innovation Potential	Science, technology and innovation human investment	Full-time equivalent of R&D personnel
		Funding for science, technology and innovation	Internal expenditure on R&D funds

(3) Control variables: In order to effectively observe the impact of the digital economy on the level of modernization of agriculture and rural areas, it is also necessary to control the following factors: industrial structure (x_1), measured by the ratio of the value added of the secondary and tertiary industries in the GDP; the level of fiscal expenditure (x_2), measured by the share of the general budget expenditure of the local finances in the GDP; the level of education (x_3), measured by the number of students receiving tertiary education per 10,000 permanent residents; environmental quality, measured by energy consumption per unit of GDP; and the quality of environment, measured by energy consumption per unit of GDP. The level of education (x_4) is measured by the number of tertiary education students per 10,000 resident population; and the quality of the environment is measured by energy consumption per unit of GDP.

(4) Mediating variables: Referring to Hu Xijuan et al. (2022)[12] on the impact of scientific and technological innovation and human capital on agricultural and rural modernization and other studies, the two mediating variables set in this paper are innovation drive (Innov) and human resources (Humcp). Innovation drive (Innov), which is measured by the number of full-time personnel engaged in R&D activities per unit of population in each region; and human resources (Humcp), which is expressed by the natural logarithmic value of the amount of financial expenditures by local governments in the field of education.

3.2. Model Setup

Referring to related literature, the digital economy promotes the modernization of agriculture and rural areas by accelerating innovation drive and optimizing human resources. To test this mechanism, this paper establishes a two-way fixed effects model in the following form:

$$y_{it} = m_0 + m_1x_{it} + \lambda X_{it} + v_i + e_t + \varepsilon_{it}$$

Where y_{it} denotes the level of agricultural and rural modernization in province i in period t , x_{it} denotes the level of digital economy development in province i in period t , e_t represents time fixed effects, v_i represents individual fixed effects, and ε_{it} is a random perturbation term.

To further test the mediating effect of innovation drive and human resources, this paper constructs the following mediating effect model:

$$y_{it} = a_0 + a_1x_{it} + \lambda X_{it} + v_i + e_t + \varepsilon_{it} \quad (1)$$

$$MED_{it} = b_0 + b_1x_{it} + \theta X_{it} + v_i + e_t + \varepsilon_{it} \quad (2)$$

$$y_{it} = c_0 + c_1x_{it} + \varphi MED_{it} + \delta X_{it} + v_i + e_t + \varepsilon_{it} \quad (3)$$

Where *MED* denotes the mediating variables, i.e. innovation drive (Innov) and human resources (Humcp). Equation (1) is used to test the direct effect of the level of digital economy development on the level of agricultural and rural modernization; equation (2) is used to test the effect of the level of digital economy development on the mediating variables; and equation (3) is used to test the effect of the mediating variables on the level of agricultural and rural modernization after controlling for the effect of digital economy.

3.3. Data Description

The data in this paper comes from the panel data of 31 provinces in China from 2011-2023 by the National Bureau of Statistics, and the data coverage is complete. The level of modernization of agriculture and rural areas (*y*) is synthesized into a composite index by assigning and standardizing the four dimensional indicators of industry, production, life, and governance through the entropy method; and the index of digital economy development (*x*) is constructed from the three dimensions of digital infrastructure, the degree of application, and the potential for innovation using the principal component analysis method. Among the mediating variables, innovation drive (Innov) is measured by the number of full-time personnel engaged in R&D activities per unit of population in each region, and human resources (Humcp) is measured by the natural logarithmic value of the amount of financial expenditures by local governments in the field of education. Control variables cover industrial structure (x_1), level of fiscal spending (x_2), level of education (x_3) and environmental quality (x_4).

The results show that the average value of the level of agricultural and rural modernization is 0.512, and the standard deviation reaches 0.113, reflecting the obvious imbalance in the process of advancing agricultural modernization in various regions; the average value of the digital economy index of all provinces in the country is 0.461, and the standard deviation is 0.115, which further confirms the significant difference in the degree of digital economy development between regions; the minimum value is 0.211, and the The maximum value is 0.832, indicating that the development of digital economy in some provinces is more leading, while the digital economy in some provinces is still in its infancy. Among the control variables, the mean value of education level (x_3) is 0.577, and the standard deviation is 0.058, indicating that there are some differences in the education level of each province; the mean value of industrial structure (x_1) is 0.646, and the standard deviation is 0.079, indicating that there are some differences in the industrial structure of each province, but the second and third industries account for a higher proportion on the whole.

4. EMPIRICAL RESULTS AND ANALYSIS

4.1. Base Regression Analysis

Based on the two-way fixed effects model, the study found that there is a positive driving effect of the digital economy development index (*x*) on the level of agricultural and rural modernization. The regression coefficient of digital economy development index (*x*) is 0.301, which is significant at 1% statistical level. This indicates that every one unit increase in the digital economy will lead to a significant increase of 0.301 units in the level of agricultural rural modernization, which verifies hypothesis H1, that is, there is a significant positive driving effect of the digital economy on agricultural rural modernization.

Among the control variables, the coefficients of industrial structure (x_1) and education level (x_3) are significantly positive, which suggests that the increase in the proportion of secondary and tertiary industries as well as the popularization of higher education positively affects the modernization of rural agriculture. And the coefficient of environmental quality (x_4) is significantly negative, indicating that the improvement of environmental quality is equally important for agricultural rural modernization.

These results show that the development of the digital economy not only directly promotes the modernization of agriculture and rural areas, but also indirectly promotes the process of modernization of agriculture and rural areas through optimizing the industrial structure, upgrading the level of education and improving the quality of the environment.

4.2. Robustness Check

To ensure the robustness of the benchmark results, this study was tested through the following three methods.

(1) Stepwise regression method: by gradually introducing control variables, we find that the coefficient of digital economy consistently remains between 0.208 and 0.325 and is statistically significantly positive. This indicates that the impact of the digital economy on the research results remains robust even after controlling for other variables, with no significant change in the level of significance.

(2) Replacement of the estimation model: this study uses random effects model and mixed OLS method for re-testing respectively. The regression coefficients of the digital economy variables are 0.287 and 0.301 respectively, both of which pass the test at the 1% significance level ($p < 0.01$), and their directions and magnitudes are highly consistent with the baseline estimates. This multi-method validation process effectively strengthens the robustness of the empirical findings.

(3) Excluding some samples: In order to exclude the possible influence of specific samples, this study re-estimates the model after excluding the samples of four municipalities with special administrative status, namely Beijing, Shanghai, Tianjin and Chongqing. The empirical results show that the coefficient of digital economy is 0.305, which is significant at 0.1% significance level ($p = 0.000$), indicating that the research results are still robust even after excluding these special samples.

4.3. Heterogeneity Analysis

By deeply exploring whether there are regional differences in the impact of digital economy on Chinese-style agricultural rural modernization, this paper divides the sample into three regions according to regions: east, central and west, and conducts regression analysis separately. The regression results show that the digital economy has the most significant contribution to agricultural rural modernization in the eastern region, with a coefficient of 0.402 and statistically significant at the 5% significance level. The central (0.285) and western (0.198) regions maintain statistical significance ($p < 0.05$), but the intensity of the effect decreases to different degrees, respectively.

This difference may be closely related to the relatively well-developed digital infrastructure and the wide range of technological applications in the eastern region. Given the higher level of economic development in the eastern region, its digital transformation started earlier, and thus the modernization process of agriculture and rural areas has been accelerated and developed at a relatively fast pace under the impetus of the digital economy. In contrast, the enabling effect of the digital economy is weaker in the central and western regions due to the relative lag in infrastructure development and the low level of technology adoption.

5. MECHANISM ANALYSIS

Based on the mediation effect model, the results show that the coefficients of the digital economy on innovation drive (Innov) and human resources (Humcp) are 0.136 and 0.217, respectively, which are both significant at the 1% significance level ($p < 0.01$). This indicates that the digital economy significantly contributes to innovation-driven and human resource development. Further analysis reveals that after adding the mediating variables, the direct effect of digital economy on agricultural and rural modernization decreases to 0.251 ($p < 0.01$), and the mediating effects of innovation-driven and human resources are 0.038 and 0.068, respectively, accounting for 15.4% and 21.8% of the total effect. This indicates that the digital economy indirectly promotes agricultural and rural modernization by stimulating innovation capacity and enhancing human capital, validating hypotheses H2 and H3.

Specifically, the digital economy promotes the process of agricultural and rural modernization by accelerating innovation drive. The coefficient of innovation drive as a mediating variable is 0.048, indicating that the improvement of innovation ability has a significant driving effect on agricultural rural modernization. In addition, the digital economy further enhances agricultural rural modernization by optimizing the allocation of human resources. Human resources, as another mediating variable, has a coefficient of 0.068, showing that the enhancement of human capital has an important role in promoting rural agricultural modernization.

6. CONCLUSIONS AND RECOMMENDATIONS OF THE STUDY

This paper conducts an in-depth study around the digital economy empowering China's agricultural and rural modernization, and conducts empirical analysis by constructing an agricultural and rural modernization evaluation index system and a mediation effect model, combined with panel data from 31 provinces, municipalities and autonomous regions across the country in the period of 2011-2023. The study finds that, firstly, the popular application of digital technology in agricultural production has not only dramatically improved the efficiency of agricultural production, but also effectively improved the rural industrial layout, which provides a direct impetus to promote the modernization of agriculture and rural areas. Second, the vigorous development of the digital economy has strongly stimulated the intrinsic motivation of agricultural scientific and technological innovation, significantly accelerated the transformation of agricultural scientific and technological achievements into actual productivity, and then promoted the expansion of the agricultural industry chain and the enhancement of the added value of the industry, which indirectly promotes the modernization of agriculture and rural areas. Third, the development of the digital economy has attracted high-quality talents to return to the rural villages, improved the digital skills and comprehensive quality of the rural labor force, and provided talent support for the modernization of agriculture and rural areas. Further analysis shows that, fourth, the promotion effect of the digital economy on agricultural and rural modernization varies in different regions, with the greatest positive promotion effect on the central region, followed by the western region and the eastern region.

Based on the findings of this paper, the following recommendations can be made:

First, it is recommended that investment in digital infrastructure in rural areas be increased, and that the rate of broadband access to the Internet and the coverage of mobile communication facilities be improved; efforts should be made to optimize policy supply, strengthen support for emerging agricultural business forms, and focus on supporting digital agricultural technology innovation and the construction of rural e-commerce platforms. Through the establishment of a sound policy guarantee mechanism, the deep integration of rural primary, secondary and tertiary industries will be promoted, laying a solid institutional foundation for digital economy-driven modernization of agriculture and rural areas.

Second, encourage and support the application and innovation of digital technology in agriculture, strengthen the research and development and promotion of agricultural science and technology, accelerate the transformation of agricultural scientific and technological achievements, enhance the total factor productivity of agriculture, rely on information technology to promote the research and development of key core technologies in agriculture, set up an innovation service platform for the digital economy, and promote the transformation and application of agricultural scientific and technological achievements, and shift from crude growth relying on resource inputs to scientific and technological innovation-led Connotative development. At the same time, efforts should be made to build a rural human resources development system, focusing on strengthening digital skills training, systematically improving the information technology application ability and comprehensive professionalism of agricultural practitioners, so that they can better adapt to the requirements of the development of the digital economy. In addition, we should improve the talent introduction mechanism and formulate competitive incentive policies to attract young people with higher education backgrounds, returning migrant workers with rich practical experience and entrepreneurs with modern management concepts to return to the countryside.

Thirdly, in view of the significant differences in the modernization of agriculture and rural areas in various regions of China, a locally tailored strategy for the development of the digital economy should be implemented. For the central and western regions, we should focus on strengthening policy support and tilting resources, focusing on improving the construction of digital rural infrastructure, coordinating the deployment and application of new-generation information technology such as the Internet of Things, cloud computing, mobile Internet and other information technologies, building a perfect digital support system, improving the efficiency of digital transformation of agriculture and rural areas and the comprehensive production capacity of agriculture, and narrowing the inter-regional digital divide. For the eastern region, it is necessary to optimize the allocation of digital economic resources, avoid the "crowding effect" caused by excessive concentration of resources, and guide the rational flow of advantageous digital economic resources to the agricultural and rural areas, so as to further promote the modernization process of agriculture and rural areas.

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