Article

The Impact of Agricultural Digitization on the High-Quality Development of Agriculture: An Empirical Test Based on Provincial Panel Data

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Abstract: To study the impact mechanism and effect of agricultural digitization on the agricultural field plays a vital role in achieving the target of high-quality agricultural development. There are three perspectives that can be taken to construct the framework of analysis as to the impact mechanism of agricultural digitization on the high-quality development of agriculture: enhancing agricultural production efficiency, optimizing resource allocation and upgrading the industrial structure. Besides, the threshold effect of the education level of the labor force is also analyzed. Based on China’s provincial panel data from 2011 to 2020, the two-way fixed effects model and threshold effect test model are applied to verify the research hypothesis. It has been discovered that agricultural digitization is conducive to promoting the high-quality development of agriculture. Heterogeneity analysis shows that agricultural digitization plays a more significant role in the eastern region than in the central and western regions. There is a single threshold effect that depends on the education level of the rural labor force in the promotion of agricultural digitization to high-quality agricultural development. When the threshold is exceeded, agricultural digitization plays a more significant role in promoting high-quality agricultural development. There are three policy suggestions made to conclude the study. The first one is to improve the construction of agricultural digitization infrastructure. The second one is to pay attention to the differences in the development degree and demand between regions in the process of agricultural digitization construction. The last one is to improve the quality of the rural labor force and the input of scientific and technological talents in the agricultural industry.

Keywords: agricultural digitization; high-quality development of agriculture; labor force quality; two-way fixed effects model; threshold effect

1. Introduction

China has made remarkable achievements in agricultural production, which plays an important role in ensuring national food security. However, China’s agricultural development remains faced with various practical problems, such as rigid resource constraints, low economic benefits, frequent natural disasters, and serious agricultural non-point source pollution [1]. These problems further lead to the conflict between population, resources, environment and economic development, which has become the main obstacle to the comprehensive, coordinated and sustainable development of both economy and society in China [2]. To achieve sustainable agricultural development, it is necessary to promote the transformation from traditional agriculture to modern agriculture [3]. The high-quality development of agriculture is beneficial to the sustainable development of the agricultural industry, given the limited carrying capacity of water and soil resources. Such a development mode is considered an inevitable choice to address the difficulties in economic transformation and promote rural revitalization. Therefore, it is undoubtedly of much practical significance to improve the level of high-quality agricultural development by exploring the driving mechanism and path to policy optimization.
The existing studies focus mainly on the connotation, internal motivation and external influencing factors of high-quality agricultural development. In terms of its connotation, high-quality agricultural development is characterized mainly by the improvement of supply quality and efficiency, large-scale production, industrial diversification and integration, and green development [4]. The stable, sustainable and green development of agriculture can be achieved by improving agricultural production efficiency and organizational efficiency [5], optimizing and upgrading agricultural and industrial structure, as well as promoting the diversified development of the agricultural industry [6]. The high-quality development of agriculture is a systematic project that covers agricultural production, operation and industry [7,8]. The endogenous factors in high-quality agricultural development include not only the positive factors such as industrial restructuring [9], the optimization of input factors [10], the effective utilization of agricultural subsidies [11,12], socialized services [13], the investment in scientific agricultural technologies [14] and agricultural product processing industry cluster [15] but also various inductive factors such as the aging of rural labor force [16], which play a negative role. The external influencing factors in high-quality agricultural development include policy guidance [17] and new urbanization development [3], etc. In addition to addressing the blocking effect of the business model adopted by individual farmers on the application of new technologies [18], high-quality agricultural development can also meet the increasingly diversified needs of different stakeholders [19], which is essential for rural revitalization. With the constant improvement of agricultural digital service systems and the application of digital technologies such as the Internet of Things, big data, cloud computing, and artificial intelligence in agricultural production, the digital transformation of agricultural production is deepened. Agricultural digitization has a significant impact on various aspects of the agricultural system, such as production efficiency [20], circulation, management, service and others [21,22]. Agricultural digitization contributes significantly to resolving the dilemma faced by agricultural development by expanding the sales market [23], creating new jobs [24], and increasing the capacity of agricultural ecological services [25]. The advance in agricultural digitization can change the traditional mode of agricultural production [26] and agricultural information sharing [27], promote the transformation and development of agriculture and improve the level of high-quality agricultural development.

Despite the theoretical analysis conducted in recent years by some scholars as to the impact of agricultural digitalization on the high-quality development of agriculture [28,29], there is still a lack of the necessary empirical tests on these theoretical mechanism summaries. In addition, it may lead to heterogeneity in the impact of agricultural digitization on high-quality agricultural development due to the significant differences in the level of factor resources among different provinces in China, especially in the education level of rural labor as the main body of digital technology dissemination and application. In this study, a systematic review is conducted on the mechanism and path of agricultural digitization for the high-quality development of agriculture. Besides, a comprehensive evaluation index system is constructed in this study to analyze the effect of heterogeneity in agricultural digitization on high-quality agricultural development. Through an analysis of the threshold effect of agricultural digitization on high-quality agricultural development given different education levels of the rural labor force, theoretical reference is provided for achieving high-quality agricultural development.

The contributions of this study include the following points. Firstly, the impact mechanism of agricultural digitization on high-quality agricultural development is systematically analyzed. Secondly, the role of agricultural labor quality in the realization of high-quality agricultural development is analyzed. Lastly, a reference is provided for achieving sustainable, high-quality agricultural development.

2. Theoretical Analysis and Research Hypothesis

Agricultural digitization refers to modern agriculture where remote sensing, geographic information system, global positioning system, computer technology, communica-
tion and network technology, automation technology and other high and new technologies are taken as agricultural production factors, with modern information technology applied to visualize, digitize and manage agricultural production process, production environment, agricultural product sales and circulation. Agricultural digitization is beneficial not only to the rational utilization of various agricultural resources but also to the reduction in production costs and sales costs of agricultural products. At the same time, it contributes to preserving the ecological environment, improving the quality of crop products, and expanding the sales channels of agricultural products [20–29].

(1) Advanced digital technology is applied to improve agricultural production efficiency and achieve the high-quality development of production systems. Agricultural digitization plays a key role in promoting the comprehensive utilization of modern production technology and traditional agricultural production factors, adjusting the mode of agricultural production, and achieving precision agricultural production [30,31]. Agricultural production entities can take advantage of the agricultural big data system, satellite remote sensing, unmanned aerial vehicle and other tools to collect data and images related to agricultural product planting conditions, growth status and natural disaster prediction, etc. Remote real-time monitoring and tracking can be carried out through smartphones, computers and other intelligent devices to achieve an intelligent perception of agricultural production. Apart from that, agricultural production entities can conduct scientific analysis based on big data systems, formulate decision-making plans on production accurately and flexibly, lower agricultural production costs, as well as improve the efficiency of agricultural production and resource utilization [32]. In addition, the precise control of digital agriculture is also beneficial to reduce agricultural pollution and increasing the output of high-standard agricultural products. On the one hand, agricultural factor input, especially agricultural chemicals input, is a major contributor to agricultural carbon emissions [33,34]. Through the precise control of digital agriculture, the excessive use of agricultural chemicals can be restricted, and the negative externalities of agricultural production can be reduced. On the other hand, as the income level of urban and rural residents improves in China, there has been a comprehensive upgrading to China’s consumer market structure and consumer concept, which requires high-quality agricultural development. By applying precise control on digital agriculture, greener, pollution-free and high-standard agricultural products are outputted to meet the new consumption needs of consumers. At the same time, the well-developed digital facility system in rural areas can help promote the informatization of education received by farmers on production technology, break through the time and geographical restrictions, as well as reduce the time cost and material cost of knowledge acquisition for farmers. They can learn more advanced technologies and concepts relating to agricultural production, which is conducive not only to the promotion and application of various modern production technologies in agricultural production but also to the high-quality development of agricultural production systems.

(2) The high-quality development of the business system can be achieved by promoting the reform of the agricultural business system and optimizing the allocation of resource elements. Agricultural digitization leads to the change in factor input combination mode, which is effective in breaking the constraints on resources required for agricultural development. In this way, a new mode of production factor allocation can be formed [35]. From the perspective of labor resource allocation, the development of agricultural digitization has promoted the differentiation of the rural labor force by enhancing agricultural production links and improving the level of agricultural division and specialization [11]. That is to say, those farmers with high agricultural production level work in the agricultural industry, and the rest of the labor force is transferred to employment. Therefore, the efficiency of labor productivity is improved through optimal labor allocation. From the perspective of agricultural land resource allocation, the differentiation and mobility of the rural labor force also promote the large-scale transfer of rural land. Land shifts from the farmers with low production efficiency to those with high production efficiencies, such as major grain growers, specialized agricultural enterprises and other modern agricultural
production organizations. In this way, the efficiency of agricultural land use is improved. From the perspective of material allocation, digital technology has the characteristics of material accumulation, which is conducive to attracting more professional talents, high-end technology, equipment and plants and other agricultural production factors [36]. Under the policy on strengthening agriculture, benefiting and enriching farmers, a multi-level comprehensive cooperation system has been established to improve the proportion and utilization efficiency of material input in the agricultural operation system. In summary, agricultural digitization plays a crucial role in the reasonable allocation of agricultural resources and the high-quality development of agricultural management systems.

(3) The high-quality development of the industrial system can be achieved by promoting the expansion and extension of the agricultural industry chain as well as guiding the upgrading of the industrial structure. The popularization of digital technology in the agricultural sector gives rise to various new economic formats, thus forming a new “agricultural dividend”. Through the e-commerce platform, the e-commerce village has formed a complete development mode that features the integration of “agriculture and e-commerce”, involving design, marketing, express and other industries. The new model is conducive to expanding the sales channels of agricultural products, promoting the integration and development of traditional agriculture with manufacturing, service, logistics and other industries, as well as promoting the vertical extension of the agricultural industry chain [37]. Therefore, the clustering effect and scale effect of industrial cooperation can be achieved under the context of high-level agricultural digitization. In addition, the application of digital technology has also promoted the transformation of traditional agricultural functions, freeing agriculture from the limit of meeting people’s needs for food. It can also diversify its business functions and meet the personalized needs of consumers by developing industry models with rural characteristics, such as ecotourism and leisure agriculture. In turn, the transformation and upgrading of the agricultural industry can be promoted for high-quality development of the agricultural industry system. Based on the above analysis, the following research hypotheses are proposed in this paper.

(4) The educational level of rural labor has a significant effect on agricultural development, as they are directly involved in production [38]. The different levels of factor resources among different provinces in China are excluded from the above discussion, especially the regional differences in the education level of rural labor as the main body of digital technology dissemination and application. In fact, the education level of the rural labor force varies significantly among different regions due to the factors such as the level of social and economic development in different regions of China and the investment of education funds [39]. Given the variation in the education level of rural labor, there may be heterogeneity in the impact of agricultural digitization on high-quality agricultural development. The higher the education level of the rural labor force, the more significant the effect of agricultural digitization on the high-quality development of agriculture. This is mainly because education level produces the “endowment effect”; that is to say, a highly-educated rural labor force is inclined to accept new things, as a result of which they participate in the transformation of agricultural digitization more actively. At the same time, the rural labor force with high education levels has richer and more professional knowledge and skills, which enables them to apply digital technology more efficiently. By contrast, the rural labor force with a low education level finds it difficult to master advanced digital technology. In summary, the effect of agricultural digitization on the high-quality development of agriculture is determined by the education level of the rural labor force. At different stages of training received by the rural labor force in the region, there are threshold characteristics exhibited by its impact on agricultural digitization to promote the high-quality development of agriculture. Therefore, the following research hypothesis is proposed in this paper.

Agricultural digitization is beneficial to promote the high-quality development of agriculture. Affected by the cultural quality of the rural labor force, agricultural digitization has a threshold effect on the promotion of high-quality agricultural development.
3. Materials and Methods
3.1. Analytical Methods

(1) Benchmark model: the following benchmark regression models are constructed in this study to test the impact of agricultural digitization on high-quality agricultural development:

\[ Ag_{it} = \beta_0 + \beta_1 \text{Dig}_{it} + \beta_2 \text{Controls}_{it} + \mu_i + \omega_t + \epsilon_{it} \] (1)

where \( Ag \) represents the high-quality development level of agriculture; \( \text{Dig} \) indicates the level of agricultural digitization; \( \text{Controls} \) denotes other control variables; \( \mu \) and \( \omega \) are referred to as the variables of province and year, respectively, to control individual effect and time effect; \( \epsilon \) indicates a random disturbance term; \( i \) refers to the province; \( t \) refers to the year.

(2) Considering the threshold model of the education level of the rural labor force, the following panel threshold regression model is constructed in this study based on the benchmark model to confirm the second part of the research hypothesis. By referring to Hansen’s modeling ideas [40], the rural labor force education level (Edu) is taken as the threshold variable:

\[ Ag_{git} = \beta_0 + \beta_1 \text{Dig}_{it} I(Edu_{it} \leq \eta_1) + \beta_2 \text{Dig}_{it} I(\eta_1 < Edu_{it} \leq \eta_2) + \cdots + \beta_n \text{Dig}_{it} I(\eta_{n-1} < Edu_{it} \leq \eta_n) + \beta_{n+1} \text{Dig}_{it} I(\eta_n < Edu_{it}) + \text{Controls}_{it} + \epsilon_{it} \] (2)

where \( I(x) \) represents the indicating function. When the conditions in the brackets are met, the value is 1; otherwise, the value is 0. Other variables are consistent with Equation (1).

3.2. Variables

(1) Explained Variable: the high-quality development of agriculture. According to the discussion about how agricultural digitization promotes high-quality agricultural development in the previous mechanism analysis based on the existing research results [41,42], a comprehensive evaluation index system of the first-level indicators and 13 second-level indicators is constructed for the high-quality agricultural development of agricultural production system, operation system and industrial system, so as to measure the level of high-quality agricultural development in each province. The entropy method is also used to determine index weight. Table 1 details the indicator system.

<table>
<thead>
<tr>
<th>Level I</th>
<th>Level II</th>
<th>Index Meaning and Calculation Method</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production system</td>
<td>Agricultural mechanization level</td>
<td>Comprehensive utilization rate of agricultural farming income</td>
<td>0.043</td>
</tr>
<tr>
<td></td>
<td>Agricultural production consumption</td>
<td>Intermediate agricultural consumption/total agricultural output value</td>
<td>0.028</td>
</tr>
<tr>
<td></td>
<td>Multiple cropping index of cultivated land</td>
<td>Crop sown area/cultivated area</td>
<td>0.049</td>
</tr>
<tr>
<td></td>
<td>Food production capacity</td>
<td>Grain yield/grain sown area</td>
<td>0.034</td>
</tr>
<tr>
<td>Business system</td>
<td>Land transfer level</td>
<td>Land transfer rate</td>
<td>0.067</td>
</tr>
<tr>
<td></td>
<td>Financial support level</td>
<td>Financial expenditure on agriculture/total financial expenditure</td>
<td>0.047</td>
</tr>
<tr>
<td></td>
<td>Proportion of agricultural technicians</td>
<td>Number of agricultural technicians/rural population</td>
<td>0.095</td>
</tr>
<tr>
<td></td>
<td>Per capita investment in fixed assets</td>
<td>Per capita investment in agricultural fixed assets of rural households</td>
<td>0.143</td>
</tr>
<tr>
<td></td>
<td>Quantity of cultivated land resources</td>
<td>Cultivated land area/rural population at the end of the year</td>
<td>0.157</td>
</tr>
<tr>
<td>Industrial system</td>
<td>Agricultural output value level</td>
<td>Total agricultural output value/rural population</td>
<td>0.065</td>
</tr>
<tr>
<td></td>
<td>Output value of agricultural and sideline products processing industry</td>
<td>Total output value of agriculture, forestry, animal husbandry and fishery services/total agricultural output value</td>
<td>0.065</td>
</tr>
<tr>
<td></td>
<td>Development level of agricultural production service industry</td>
<td>Output value of planting industry/total agricultural output value</td>
<td>0.133</td>
</tr>
<tr>
<td></td>
<td>Agricultural industrial structure</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
(2) Explanatory variable: agricultural digitization. It is difficult to evaluate the digital extent of agricultural production directly, especially when a comparison is made among different regions [43]. In spite of this, it is still possible to evaluate the material and financial basis of digital agriculture. Based on the practices in the existing literature [44], the evaluation index system of agricultural digitization level is constructed in two dimensions. One is the material basis for digital agriculture, and the other is the financial basis for digital agriculture. These indicators are listed in Table 2.

Table 2. Evaluation index system of agricultural digitalization.

<table>
<thead>
<tr>
<th>Level I Indicators</th>
<th>Secondary Indicators</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material basis of digital agriculture</td>
<td>Average computer ownership per 100 rural households</td>
<td>0.142</td>
</tr>
<tr>
<td></td>
<td>Average number of mobile phones owned by rural households per 100 households</td>
<td>0.063</td>
</tr>
<tr>
<td></td>
<td>Rural broadband access users</td>
<td>0.364</td>
</tr>
<tr>
<td></td>
<td>Length of rural delivery route</td>
<td>0.097</td>
</tr>
<tr>
<td>Financial basis for digital agriculture</td>
<td>Digital inclusive financial payment index</td>
<td>0.095</td>
</tr>
<tr>
<td></td>
<td>Digital inclusive financial insurance index</td>
<td>0.079</td>
</tr>
<tr>
<td></td>
<td>Digital inclusive financial credit index</td>
<td>0.150</td>
</tr>
</tbody>
</table>

(3) Threshold variable: the education level of the labor force. The education level of the labor force is indicated by the level of workers’ acceptance of cultural and educational activities. Therefore, it can be measured by the average education level of the rural labor force. The calculation method is expressed as

\[ \text{Edu} = \sum_j p_j \times e_q \] (3)

where Edu refers to the average length of schooling of the rural labor force; \( p_j \) denotes the proportion of the rural labor force with the education level of \( j \), \( j = 1, 2 \ldots, 5 \), respectively, indicating the five different education levels of the rural labor force: illiteracy, primary school, junior high school, high school and college or above; and \( e_q \) indicates the weight of each level of education. Considering the time required for different levels of education, the weights of the five levels of education are set to 1, 6, 9, 12 and 16, respectively.

(4) Control variables: in addition to the core explanatory variables, the following control variables are also used in this study. (1) Rural economic development level: measured by the per capita disposable income of rural residents, with the natural logarithm applied. (2) Disaster situation: measured by the crops disaster area, with the natural logarithm applied. (3) Poverty situation of farmers: measured by the Engel coefficient of rural households. (4) Urbanization level: measured by the ratio of the urban population to the total population.

3.3. Data Resources

Considering the availability and continuity of data, this study involves the sample data of 30 provinces in China from 2011 to 2020, excluding Tibet, Hong Kong, Macao and Taiwan. Most of the relevant original data in the sample are sourced from “China Statistical Yearbook”, “China Rural Statistical Yearbook”, “China Agricultural Machinery Industry Yearbook”, “China Population and Employment Statistical Yearbook”, “China Rural Business Management Statistical Yearbook”, “China Science and Technology Statistical Yearbook”, and “China Tertiary Industry Statistical Yearbook”. As for the missing data, they are supplemented by linear interpolation.

Table 3 shows the statistics of each variable. In order to prevent the reliability of the estimation results from being affected by the multi-collinearity among the multiple variables in the regression model, the collinearity diagnosis is conducted for each explanatory
variable in advance. The collinearity diagnosis results show that the variance inflation factor (VIF) of each variable is far smaller than 10. Therefore, it is considered that multicollinearity is non-existent. As shown in Table 2, the standard deviation of each variable falls below the mean value during the study period, which indicates the stability of the data. In terms of the variables related to high-quality agricultural development, the average value from 2011 to 2020 is 0.303, indicating that the level of high-quality agricultural development remains low in China. Concerning the variables related to agricultural digitization, the average value from 2011 to 2020 is 0.332, and the difference between the maximum value and the minimum value is 0.827. It reflects a significant variation in the level of agricultural digitization among different provinces in China.

Table 3. Descriptive Statistics.

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Symbol</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>High quality development of agriculture</td>
<td>Ag</td>
<td>0.303</td>
<td>0.092</td>
<td>0.148</td>
<td>0.640</td>
</tr>
<tr>
<td>Agricultural digitalization</td>
<td>Dig</td>
<td>0.332</td>
<td>0.104</td>
<td>0.040</td>
<td>0.827</td>
</tr>
<tr>
<td>Education level of labor force</td>
<td>Edu</td>
<td>7.887</td>
<td>0.581</td>
<td>6.119</td>
<td>9.939</td>
</tr>
<tr>
<td>Rural economic development level</td>
<td>Eco</td>
<td>10.310</td>
<td>0.315</td>
<td>9.615</td>
<td>11.244</td>
</tr>
<tr>
<td>Disaster situation</td>
<td>Dis</td>
<td>6.313</td>
<td>1.709</td>
<td>0</td>
<td>8.838</td>
</tr>
<tr>
<td>Poverty situation of farmers</td>
<td>Pov</td>
<td>3.905</td>
<td>0.164</td>
<td>3.170</td>
<td>3.938</td>
</tr>
<tr>
<td>Urbanization level</td>
<td>Urb</td>
<td>0.581</td>
<td>0.125</td>
<td>0.345</td>
<td>0.896</td>
</tr>
</tbody>
</table>

4. Results

4.1. Agricultural Digitalization and High-Quality Development of Agriculture

(1) Agriculture digitization. Figure 1 shows the trend of changes in China’s agricultural digitization level from 2011 to 2020. Overall, the level of agricultural digitization in the study period showed an upward trend, with the average increasing from 0.134 to 0.496. It is indicated that there has been some progress made by China in agricultural digitization. At the same time, however, it is also worth noting that agricultural digitization in China remains in the early stage, implying significant room for improvement.

Figure 1. Trends of China’s agricultural digitalization level from 2011 to 2020.

(2) The high-quality development of agriculture. Figure 2 shows the trend of changes in the level of high-quality agricultural development in China from 2011 to 2020. In general, the level of high-quality agricultural development during the study period showed an upward trend, with the average rising from 0.253 to 0.362. It indicates the continuation of significant improvement in agricultural development in China. In terms of regional values, the level of high-quality agricultural development from high to low in the central
region, the eastern region, and the western region, indicating the prominent imbalance of high-quality agricultural development in China.

![Figure 1. Trends of China’s agricultural digitalization level from 2011 to 2020.](image)

4.2. Benchmark Regression Analysis

Table 4 shows the benchmark regression results of agricultural digitization for high-quality agricultural development. According to the results of OLS without other control variables involved, the estimation coefficient of agricultural digitization (Dig) is significantly positive at the 1% statistical level. The results of OLS with other control variables involved remain unchanged, which suggests that the improvement of agricultural digitization is beneficial to promote the high-quality development of agriculture. In addition, from the perspective of control variables, the estimation coefficient of the rural economic development level (Eco) is significantly positive. A possible reason for this is that favorable rural economic conditions can promote high-quality agricultural development. The estimated coefficient of urbanization level (Urb) is also found to be significantly positive. A possible reason for this is that a higher urbanization level reflects a more prosperous market economy to some extent. A prosperous market economy is conducive to promoting high-quality agricultural development through the free flow of factors between urban and rural areas. The estimation coefficient of disaster-affected conditions (Dis) is found to be significantly negative, as is the estimation coefficient of farmers’ poverty status (Pov). The possible reason for this is that those farmers trapped in poverty struggle to fund the capital investment required for agricultural modernization transformation, which hinders the high-quality development of agriculture.

![Figure 2. Trends of China’s high-quality agricultural development level from 2011 to 2020.](image)

Table 4. Benchmark regression results.

<table>
<thead>
<tr>
<th>Variables</th>
<th>OLS without Other Control Variables</th>
<th>OLS with Other Control Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dig</td>
<td>0.510 *** (0.052)</td>
<td>0.271 *** (0.066)</td>
</tr>
<tr>
<td>Eco</td>
<td></td>
<td>0.089 *** (0.024)</td>
</tr>
<tr>
<td>Dis</td>
<td></td>
<td>−0.029 *** (0.004)</td>
</tr>
<tr>
<td>Pov</td>
<td></td>
<td>−0.207 ** (0.081)</td>
</tr>
<tr>
<td>Urb</td>
<td></td>
<td>0.125 ** (0.061)</td>
</tr>
<tr>
<td>Province</td>
<td>Control</td>
<td>Control</td>
</tr>
<tr>
<td>Year</td>
<td>Control</td>
<td>Control</td>
</tr>
<tr>
<td>Constant</td>
<td>0.101 *** (0.021)</td>
<td>1.049 *** (0.233)</td>
</tr>
<tr>
<td>Number of samples</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.644</td>
<td>0.677</td>
</tr>
</tbody>
</table>

Note: **, *** are significant at 5% and 1% levels, respectively, and the robust standard error values are in brackets.
5. Discussion

5.1. Robustness Test and Endogenous Treatment

(1) The model is replaced. Considering the value of high-quality agricultural development (explained variable) as measured in this study to range between 0 and 1, which meets the conditions of the restricted dependent variable model, re-estimation is made using the Tobit model of the restricted variable model. The results are shown in Table 5. By comparing the estimation results of the Tobit model and benchmark model, it can be discovered that the influence direction of the estimated coefficient of agricultural digitization remains unchanged. The estimation results, as obtained after the model is replaced, are consistent with the conclusions based on the benchmark results.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Tobit Model</th>
<th>Municipalities Are Excluded from Samples</th>
<th>Lagging One Period of Core Explanatory Variables</th>
<th>System GMM</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAgr</td>
<td></td>
<td></td>
<td></td>
<td>0.296 *** (0.073)</td>
</tr>
<tr>
<td>Dig</td>
<td>0.271 *** (0.068)</td>
<td>0.277 *** (0.070)</td>
<td></td>
<td>0.285 *** (0.029)</td>
</tr>
<tr>
<td>Eco</td>
<td>0.089 *** (0.024)</td>
<td>0.096 *** (0.028)</td>
<td></td>
<td>0.064 *** (0.022)</td>
</tr>
<tr>
<td>Dis</td>
<td>−0.029 *** (0.004)</td>
<td>−0.033 *** (0.006)</td>
<td></td>
<td>−0.048 *** (0.016)</td>
</tr>
<tr>
<td>Pov</td>
<td>−0.207 *** (0.080)</td>
<td>−0.174 ** (0.085)</td>
<td>−0.220 ** (0.093)</td>
<td>−0.156 ** (0.075)</td>
</tr>
<tr>
<td>Urb</td>
<td>0.128 ** (0.064)</td>
<td>0.227 *** (0.079)</td>
<td>0.134 ** (0.062)</td>
<td>0.087 ** (0.041)</td>
</tr>
<tr>
<td>Constant</td>
<td>1.049 *** (0.231)</td>
<td>1.141 *** (0.272)</td>
<td>0.874 *** (0.277)</td>
<td>0.951 *** (0.266)</td>
</tr>
<tr>
<td>AR (1)</td>
<td>0.18</td>
<td></td>
<td></td>
<td>0.433</td>
</tr>
<tr>
<td>AR (2)</td>
<td>0.199</td>
<td></td>
<td></td>
<td>0.199</td>
</tr>
<tr>
<td>Hansen test</td>
<td>Number of samples</td>
<td>300</td>
<td>260</td>
<td>270</td>
</tr>
<tr>
<td>R²</td>
<td>0.632</td>
<td>0.825</td>
<td></td>
<td>0.825</td>
</tr>
</tbody>
</table>

Note: **, *** are significant at the 5% and 1% levels, respectively, and the robust standard error values are in brackets.

(2) Municipalities are excluded from the samples. Considering the significant difference in the agricultural production and operation activities of municipalities directly under the Central Government from other provinces, the sample data of Beijing, Tianjin, Shanghai and Chongqing are further excluded from this study. The remaining 260 sample data are used for re-estimation. The results are shown in Table 5. After the introduction of control variables and fixed effects, the estimated coefficient of agricultural digitization remains significantly positive at the 1% statistical level, and the research conclusion remains valid.

(3) Lagging one period of core explanatory variables. Considering a potential lag effect of the development of agricultural digitization, lagging one period of agricultural digitization as a new core explanatory variable is re-estimated. The results are shown in Table 5. After the introduction of control variables and adopting fixed effects, the estimation coefficient of agricultural digitization remains significantly positive. It shows that agricultural digitization has a certain “snowball effect”, which means the current agricultural digital development is beneficial to promote the high-quality development of agriculture in the next period.

(4) Endogenous treatment. There are two major causes of the endogenous problem encountered in this study. On the one hand, there remain some missing variables that lead to deviation in the regression results, although several control variables are controlled in this study when the model is constructed and the fixed effects of provinces and years are considered. On the other hand, despite the promoting effect of agricultural digitization on high-quality agricultural development, the level of agricultural digitization is improved with high-quality agricultural development; that is to say, there may be a two-way causal relationship between the two. Therefore, a two-step systematic GMM method is adopted to reduce the endogenous problem. When the system GMM is estimated, it is necessary to use the appropriate instrumental variables. Based on the existing research results [45], rural postal service outlets (Post) per million people are taken as the instrumental variable in this study. There are two reasons for this. On the one hand, digital information technology is
the continuation of traditional communication technology, so the distribution of traditional postal services affects the early development of agricultural digital technology to a certain extent, which meets the “relevance” requirements of instrumental variables. On the other hand, compared with the rate at which digital technology advances, there is a gradual decrease in the frequency of applying traditional information instruments for postal services. Besides, its impact on the high-quality development of agriculture continues to diminish, which meets the “exogenous” requirements of instrumental variables.

Table 5 lists the estimation results of the system GMM, the regression of which in this study is free from second-order sequence autocorrelation and over-identification. It demonstrates the reliability of the estimation results. Agricultural digitization still passes the test at a significant level of 1%, and the estimation coefficient reaches 0.285, indicating that the endogenous problem in the original model may cause an underestimate to some extent for the role of agricultural digitization in promoting the high-quality development of agriculture.

5.2. Heterogeneity Analysis

(1) Regional heterogeneity. Under the different location conditions, there may be regional heterogeneity in the impact of agricultural digitization on high-quality agricultural development. Therefore, according to the distribution characteristics of geographical locations across China, the sample data can be divided into three categories: the east, the central and the western regions. The fixed effect model is applied to test regional heterogeneity, and the regression results categorized by region are shown in Table 6. As suggested by the results, agricultural digitization plays a significant role in promoting high-quality agricultural development in the eastern and central regions. Concerning the overall situation of the country, the estimated coefficient of the eastern region exceeds the national average, while the estimated coefficient of the central region falls below the national average. In the western region, despite the positive, the estimated coefficient of agricultural digitization fails to reach a significant extent. The possible reason for this is that the level of economic development in the western region is relatively backward, so the promoting effect of agricultural digitization on high-quality agricultural development has not manifested itself in this region. It also shows the clear difference in the effect of agricultural digitization technology. The promoting effect of agricultural digitization on the high-quality development of agriculture diminishes gradually from the east to the west, with no significant impact found in the western region. It demonstrates the regional heterogeneity of promoting effect of agricultural digitization.

Table 6. Regional heterogeneity.

<table>
<thead>
<tr>
<th>Variables</th>
<th>The Eastern Region</th>
<th>The Central Region</th>
<th>The Western Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dig</td>
<td>0.388 *** (0.013)</td>
<td>0.133 ** (0.063)</td>
<td>0.181 (0.162)</td>
</tr>
<tr>
<td>Eco</td>
<td>0.079 ** (0.036)</td>
<td>0.156 *** (0.026)</td>
<td>0.082 ** (0.036)</td>
</tr>
<tr>
<td>Dis</td>
<td>−0.005 *** (0.001)</td>
<td>−0.011 ** (0.005)</td>
<td>−0.025 *** (0.009)</td>
</tr>
<tr>
<td>Pov</td>
<td>−0.143 *** (0.025)</td>
<td>−0.187 ** (0.091)</td>
<td>−0.116 *** (0.018)</td>
</tr>
<tr>
<td>Urb</td>
<td>0.233 ** (0.105)</td>
<td>0.277 *** (0.075)</td>
<td>0.167 ** (0.083)</td>
</tr>
<tr>
<td>Province</td>
<td>control</td>
<td>control</td>
<td>control</td>
</tr>
<tr>
<td>Year</td>
<td>control</td>
<td>control</td>
<td>control</td>
</tr>
<tr>
<td>Constant</td>
<td>0.594 *** (0.162)</td>
<td>1.834 *** (0.248)</td>
<td>0.135 (0.532)</td>
</tr>
<tr>
<td>Number of samples</td>
<td>110</td>
<td>80</td>
<td>110</td>
</tr>
<tr>
<td>R²</td>
<td>0.685</td>
<td>0.751</td>
<td>0.739</td>
</tr>
</tbody>
</table>

Note: ** and *** are significant at 5% and 1% levels, respectively, and the robust standard error values are in brackets.

(2) Distribution heterogeneity. Then, the panel quantile regression model is used in this study to explore the variation in the impact of agricultural digitization on the level of high-quality agricultural development at different quantile levels. The results are listed in Table 7, showing the estimated coefficients of the impact of agricultural digitization
on high-quality agricultural development at the 25%, 50%, 75% and 90% quantiles. The estimation coefficients on each quantile are found to be positive and pass the 1% significance level test. However, judging from the size of the estimation coefficient, the promoting effect of agricultural digitization on the high-quality development of agriculture shows an increasing trend of marginal utility with the increase of the quantile level.

Table 7. Panel quantile regression results.

<table>
<thead>
<tr>
<th>Variables</th>
<th>25%</th>
<th>50%</th>
<th>75%</th>
<th>90%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dig</td>
<td>0.201 *** (0.011)</td>
<td>0.228 *** (0.027)</td>
<td>0.255 *** (0.042)</td>
<td>0.581 *** (0.167)</td>
</tr>
<tr>
<td>Eco</td>
<td>0.050 ** (0.022)</td>
<td>0.094 *** (0.035)</td>
<td>0.118 *** (0.031)</td>
<td>0.253 *** (0.056)</td>
</tr>
<tr>
<td>Dis</td>
<td>−0.013 (0.011)</td>
<td>−0.031 *** (0.005)</td>
<td>−0.029 *** (0.005)</td>
<td>−0.029 *** (0.010)</td>
</tr>
<tr>
<td>Pov</td>
<td>−0.132 ** (0.061)</td>
<td>−0.246 *** (0.053)</td>
<td>−0.270 *** (0.064)</td>
<td>−0.299 *** (0.100)</td>
</tr>
<tr>
<td>Urb</td>
<td>0.024 (0.021)</td>
<td>0.054 (0.035)</td>
<td>0.105 *** (0.017)</td>
<td>0.350 *** (0.038)</td>
</tr>
</tbody>
</table>

Note: ** and *** are significant at 5% and 1% levels, respectively, and the robust standard error values are in brackets.

5.3. Threshold Effect Test Based on the Education Level of Rural Labor Force

Furthermore, the panel threshold regression model is used in this study to analyze the potential threshold effect of agricultural digitization on high-quality agricultural development due to variations in the quality of rural labor. First of all, it is necessary to test the threshold number and threshold value before threshold regression. In this study, the education level of the rural labor force (Edu) is taken as the threshold variable, and the Bootstrap method is used to test whether the threshold effect exists through the repeated sampling of 1000 times. The test results are listed in Table 8. The education level of the rural labor force passes the single threshold test at the 1% statistical level but fails the double threshold test. It indicates the necessity to construct a single threshold model for analysis, and the threshold value is 8.073. Besides, Figure 3 shows the model likelihood ratio function given a single threshold of the panel threshold model to verify the threshold estimate. The critical value of LR statistic at a 5% significance level is 7.35, and the LR value corresponding to the threshold value 8.073 falls below 7.35. Therefore, the threshold value is treated as effective.

According to the results of threshold value estimation, regression is performed using Equation (2) to estimate the threshold effect of agricultural digitization on the promotion of high-quality agricultural development. The results are listed in Table 9. Given different levels of rural labor education, there is a significant difference in the promoting effect of agricultural digitization on high-quality agricultural development. Specifically, when the education level of the rural labor force falls below the threshold (8.073), the estimated coefficient of agricultural digitization is 0.064, which is only significant at the 10% statistical level. When the education level of the rural labor force exceeds the threshold (8.073), the estimated coefficient of agricultural digitization rises to 0.281, which is significant at the 1% statistical level. It shows that the promoting effect of agricultural digitization on high-quality agricultural development is more significant when the education level of the rural labor force reaches above the threshold. In addition, by observing the education level of rural labor in various provinces across China, it can be found that by 2020, the education level of rural labor will be below the threshold in 11 out of the 30 provinces, including Inner Mongolia, Anhui, Shandong, Fujian, Chongqing, Sichuan, Guizhou, Yunnan, Gansu, Qinghai and Ningxia. Among them, one province is located in the central region, two provinces are located in the eastern region, and the other eight provinces are located in the western region (Figure 4). It suggests that some provinces in the western region are constrained by the education level of the rural labor force, thus resulting in the weak
promoting effect of agricultural digitization on high-quality agricultural development. This is not significantly consistent with the estimated coefficient of agricultural digitization in the western region in the analysis of the results of the previous “regional heterogeneity”.

Table 8. Threshold effect test.

<table>
<thead>
<tr>
<th>Threshold Variables</th>
<th>Numbers of Threshold</th>
<th>F</th>
<th>p</th>
<th>10%</th>
<th>5%</th>
<th>1%</th>
<th>Threshold Value</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edu</td>
<td>Single</td>
<td>89.36</td>
<td>0.003</td>
<td>32.902</td>
<td>41.546</td>
<td>79.430</td>
<td>8.073</td>
<td>[8.054, 8.087]</td>
</tr>
</tbody>
</table>

Figure 3. Single threshold estimate.

Table 9. Regression Results of Threshold Effect.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Ag</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dig_1 (Edu ≤ 8.073)</td>
<td>0.064 * (0.037)</td>
</tr>
<tr>
<td>Dig_2 (Edu &gt; 8.073)</td>
<td>0.281 *** (0.034)</td>
</tr>
<tr>
<td>Eco</td>
<td>0.031 *** (0.010)</td>
</tr>
<tr>
<td>Dis</td>
<td>−0.008 *** (0.002)</td>
</tr>
<tr>
<td>Pov</td>
<td>−0.073 *** (0.024)</td>
</tr>
<tr>
<td>Urb</td>
<td>0.107 *** (0.007)</td>
</tr>
<tr>
<td>Constant</td>
<td>0.273 * (0.148)</td>
</tr>
<tr>
<td>Number of samples</td>
<td>300</td>
</tr>
<tr>
<td>R²</td>
<td>0.630</td>
</tr>
</tbody>
</table>

Note: *, *** are significant at 10%, 1% levels, respectively, and the robust standard error values are in brackets.
6. Conclusions

In the present study, an attempt is made to account for the underlying mechanism of agricultural digitization promoting high-quality agricultural development. Besides, the 2011–2020 provincial panel data are used to conduct empirical tests. The main findings of the study are as follows. Firstly, agricultural digitization exerts a significant positive effect on the high-quality development of agriculture, and the conclusion remains valid after the robustness test and endogenous treatment. Secondly, there are significant regional heterogeneity and distribution heterogeneity exhibited by the promoting effect of agricultural digitization on the high-quality development of agriculture, and this promoting effect is more significant in the samples of the eastern region than in the samples of the central and western regions. Thirdly, the education level of the rural labor force produces a single threshold effect when agricultural digitization promotes high-quality agricultural development, with the threshold value reaching 8.073. When the education level of the rural labor force exceeds the threshold, agricultural digitization has a more significant positive impact on the high-quality development of agriculture.

Based on the above results, the following policy recommendations are made in this study. Firstly, the construction of digital agricultural infrastructure should be strengthened. A complete digital infrastructure plays a vital role in improving the level of agricultural digitization. The high level of digital infrastructure can compensate for the deficiencies of other facilities [46]. However, the digital infrastructure system in rural areas across China is relatively backward, so it remains necessary to increase the investment made in the construction of digital agricultural infrastructure. Specifically, the government can direct more individuals, private enterprises and other social capital to the construction of
agricultural digitization, in addition to increasing financial support. A diversified financing guarantee mechanism can be established with the active participation of the state, society and individuals to fulfill the joint role of financial funds and social capital [47,48]. In this way, the economic foundation can be reinforced for the transformation of agricultural digitization, and favorable conditions can be created for the high-quality development of agriculture. Secondly, in the process of agricultural digitization construction, attention should be paid to addressing the differences in the level of development and demand between various regions. There is a clear difference in the development degree of agricultural digitization between the eastern, central and western regions of China, and a variation in the construction cost of agricultural digitization infrastructure that local governments can bear. These factors are worth considering when the strategic goal of regional agricultural digitization is achieved. By measuring the cost and benefit, a relatively optimized regional agricultural digital development strategy can be determined, which is conducive to the construction of digital infrastructure that can best serve regional development at the minimum cost [49]. Thirdly, improving the quality of the rural labor force and the input of scientific and technological talents in the agricultural field is essential for agricultural development [50]. Whether agricultural labor would accept the changes brought about by digitization in agricultural production and master the agricultural digitization technology in production, operation and management determine whether digitization technology can be integrated into agricultural production and management. By increasing the input of scientific and technological talents in the agricultural industry, human resources guarantee is provided for agricultural digitization. This is beneficial for farmers to learn and master digital information technology and gain familiarity with the application of digital information technology in agricultural production.

Due to the limitation of data availability, the impact of agricultural digitization on the high-quality development of agriculture is tested only at the provincial level, and more details analysis is needed in the future. The threshold effect of agricultural digitization on the high-quality development of agriculture was discussed from the rural labor education level dimension. Further, government policy support, regional resource endowment and other factors may be included in the discussion.

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Conflicts of Interest: The authors declare no conflict of interest.

References
3. Appleby, M.C. Sustainable Agriculture is Humane, Humane Agriculture is Sustainable. J. Agric. Environ. Ethics 2020, 18, 293–303. [CrossRef]


42. Sarkar, A.; Azim, J.A.; Asif, A.A.; Qian, L.; Peau, A.K. Structural Equation Modeling for Indicators of Sustainable Agriculture: Prospective of a Developing Country’s Agriculture. *Land Use Policy* 2021, 109, 105638. [CrossRef]


