Research on the Impact of Digital Technology Use on Farmers' Entrepreneurship: An Empirical Study Based on CFPS

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Abstract: Digital technology has reshaped the era-specific features of farmers' entrepreneurship, but research on the long-term mechanisms by which digital technology affects farmers' entrepreneurial behavior remains insufficient. This paper constructs a theoretical analysis framework for farmers' entrepreneurship and conducts empirical tests using four waves of CFPS data from 2016 to 2022. The findings show that digital technology use has a significant positive effect on farmers' decisions to start businesses across different time spans. The result remains robust after addressing endogeneity and performing a series of robustness checks. Therefore, to stimulate rural entrepreneurial potential, China should adopt a long-term perspective, actively align digital technology provision with farmers' practical needs, and improve farmers' accessibility to science and technology.

Keywords: Farmers' Entrepreneurship; Digital Technology; Rural Revitalization; Time Span; Non-Cognitive Ability

1. Introduction

Since the No. 1 document in 2018 formally proposed the digital countryside strategy, building rural digital infrastructure, improving farmers' digital literacy, and enhancing rural digitalization have become important measures to empower high-quality rural development and realize common prosperity. In recent years the government has placed great emphasis on using digital technology to encourage farmers' entrepreneurship. The Plan for Comprehensive Rural Revitalization (2024–2027) states the need to strengthen farmers' capacity to use digital tools and to support return-home or local entrepreneurship. By 2025, the Ministry of Agriculture and Rural Affairs' Opinions on Further Deepening Rural Reform and Steadily Advancing Comprehensive Rural Revitalization further emphasize promoting farmers' use of digital technology and stimulating entrepreneurial spirit as important to rural development. The full integration of digital technology and modern agriculture promotes farmers' entrepreneurial activity, which not only helps improve farmers' social status and self-realization, but also facilitates the local transfer of rural labor, raises the level of farmers' social networks and human capital, injects new momentum into rural construction, and advances rural revitalization.

Against the backdrop of rapid development of the digital economy, foundational digital technologies such as smart manufacturing and artificial intelligence are changing traditional production and business models; data have become a new production factor. Digital technology can drive industrial upgrading and, through data factor penetration, promote enterprises' digital transformation.[1] Digital technology has thus become a new engine for mass innovation and entrepreneurship. However, regional and urban–rural imbalances have become more pronounced in the new era. The promotion and use of digital technology have not clearly narrowed these gaps; in some cases disparities have widened, manifested in lagging county economies and relative impoverishment of some farmers, posing a serious threat to coordinated and healthy social-economic development. To address this problem, empowering farmers' entrepreneurship through digital technology has become an important move to unlock rural development potential, reduce urban–rural gaps, and build a strong agricultural country. This raises questions worth theoretical and empirical investigation: How does digital technology affect farmers' entrepreneurship? What are the mechanisms? Does the impact vary across different time spans? Which farmers benefit most?

Motivated by these questions, this paper first builds a mathematical model of households' entrepreneurial choice to clarify the theoretical logic by which digital technology affects farmers'

entrepreneurship. It then empirically examines the effects and mechanisms using nonlinear moderation models and four waves of the China Family Panel Studies (CFPS) data (2016–2022), aiming to provide evidence relevant to policies that promote rural industrial revitalization and economic development through digital technology-driven entrepreneurship.

2. Literature Review

Existing research on farmers' entrepreneurship at home and abroad focuses on micro-level characteristics (entrepreneur's personal endowments and household conditions) and macro-level factors (policies and external environment). At the individual and household level, entrepreneurs' behavioral attitudes, personal values, stress resilience,[2] and family emotional characteristics influence entrepreneurial activity.[3] At the macro level, a rural entrepreneurial climate, perceived social network support, and prior entrepreneurial experience positively affect farmers' entrepreneurial intentions.[4] Policy-driven industrial agglomeration can yield sustainable effects on entrepreneurial firms.[5] Some studies argue that general cognitive ability does not significantly affect the decision to start a business; instead, choices are more driven by external sectoral regulation.[6] However, due to lagging rural education and economic development, farmers are disadvantaged in information collection, opportunity discovery, and supervision, limiting entrepreneurial vitality. CFPS data show that in 2020 the rural entrepreneurship rate was only about half that of urban residents, so new drivers are needed to overcome rural entrepreneurship constraints.

With the advent of the digital economy and promotion of the digital countryside, digital technologies—owing to openness, borderlessness, and strong interactivity—have penetrated many aspects of rural life. Digital innovation offers new paths to promote common prosperity in the digital-intelligence era. Digital technology becomes a new mechanism to address farmers' entrepreneurship constraints.[7] First, digital technology can promote family entrepreneurship by expanding information channels, improving financing, enhancing social interaction, and increasing risk tolerance.[8] Specifically, digital tools can improve farmers' information access, optimize social networks, and smooth credit channels, thus alleviating information asymmetry and improving access to production factors, which motivates entrepreneurship.[9] Second, farmers can use digital technologies to broaden social networks; social interaction plays a bridging role between digital literacy and entrepreneurial behavior[10] social interaction also expands channels—e-commerce development can attract local talent to start businesses and increase the likelihood of migrant workers returning home to start businesses[11] Some studies further note that e-commerce reduces household vulnerability to poverty, raises agricultural operating income, increases agricultural production value, and promotes human capital accumulation[12], thereby improving entrepreneurship. Online marketing for rural tourism can significantly improve business performance and provide new entrepreneurial ideas[13].

Existing research has richly explored mediating mechanisms by which digital technology affects farmers' entrepreneurship, but studies on the long-term mechanism are insufficient. Using digital technology is a long-term process; most literature uses cross-sectional or short-panel data to show initial positive effects, but discussion of long-term impacts is limited. The effects are diverse and complex and likely change with the time horizon, so it is necessary to examine the long-term effects in increasingly rich digital use scenarios.

Compared with existing studies, this paper's possible contributions are:

1) Methodologically, the literature on long-term effects needs improvement. This paper builds a theoretical model to assess the causal effect of digital technology on entrepreneurship and posits hypotheses. Using micro panel data, we estimate Probit models and, to address endogeneity, apply a nonlinear simultaneous-equations approach (FIML) to ensure result integrity.

2) Substantively, unlike most prior cross-sectional studies, this paper uses multiple time points for empirical analysis. Robustness checks compare identical time spans across different years to test whether the effect of digital technology use on entrepreneurial behavior is consistent across years, thereby enriching the understanding at the individual household level.

3. Research Design

3.1 Theoretical Model and Hypotheses

Farmers' use of digital technology increases their income and promotes entrepreneurial choice. Drawing on Jinhua Zhang[14]'s research on agricultural digital technology, this paper builds a theoretical model. Whether a farmer (or household) chooses to start a business depends on whether the returns from entrepreneurship exceed the returns from not starting a business. We specify the following model:

$$Y=Y_f-Y_w \qquad (1)$$

$$\frac{\partial Y_f}{\partial D}=\frac{\partial A(D)}{\partial D}L^\alpha K^\beta \qquad (2)$$

Under the assumption that labor and capital inputs remain unchanged, total factor productivity increases with the household's use of digital technology, and thus household income rises with D.

Let Y_w denote the income a household obtains when it does not start a business. The direct cost associated with entrepreneurship, Y_w, is then equal to that non-entrepreneurial income plus the direct cost of learning digital skills, $B(D)$.

$$Y_w=w(1+r)+B(D) \qquad (3)$$

Where w is the household wage level and r is the interest rate; w(1 + r) represents the direct cost a household incurs to start a business. Thus, if a household chooses to start a business the return must exceed the incurred cost. The basic condition is:

$$Y_f=A(D)L^\alpha K^\beta-w(1+r)-B(D)>0 \qquad (4)$$

In the context of digital rural areas, as digital infrastructure continues to improve and internet coverage increases, the state will bear part of the learning costs of farmers' use of digital technology. Therefore, we assume that the benefit of farmers using digital technology per unit time initially is greater than the learning cost of using digital technology,According to the analysis, the net benefit π(D) brought by each unit of digital technology learned by farmers is:

$$\pi(D)=\frac{\partial Y_f}{\partial D}-\frac{\partial Y_w}{\partial D}=\frac{\partial A(D)}{\partial D}L^\alpha K^\beta-\frac{\partial B(D)}{\partial D} \qquad (5)$$

As farmers continue to invest in learning digital technologies, the professionalism of digital technology usage, as well as the density and complexity of knowledge, are increasing. Farmers may have to spend more to consult relevant professionals or attend related training. Based on the analysis, we hypothesize: the marginal effect of farmers' digital usage learning cost is continuously increasing, that is, it is also an increasing function:

$$\frac{\partial B(D)}{\partial D}>0,\text{and} \ \frac{\partial^2 B(D)}{\partial D^2}>0 \qquad (6)$$

As farmers increasingly use digital technology, total factor productivity will also continue to improve. However, due to the limitations of the regions where farmers are located and market competition, the scale of farmers' entrepreneurship and their entrepreneurial income cannot grow indefinitely, which means that the derivative of the direct income Y_f brought by digital technology will not always be greater than zero. According to the analysis, we assume that the second derivative of Y_f is less than zero, that is, with the continuous use of digital technology, the marginal effect diminishes. That is:

$$\frac{\partial A(D)}{\partial D}>0, \ and \frac{\partial^2 A(D)}{\partial D^2}<0 \qquad (7)$$

Therefore, the condition for farmers to achieve the highest income by using digital technology is:

$$\pi(D)=\frac{\partial^2 Y_f}{\partial D^2}-\frac{\partial^2 Y_w}{\partial D^2}=\frac{\partial^2 A(D)}{\partial D^2}L^\alpha K^\beta-\frac{\partial^2 B(D)}{\partial D^2}=0 \qquad (8)$$

In summary, if farmers want to pursue entrepreneurial options, the maximum income brought by digital technology must exceed its costs, meaning that at minimum, the following two conditions must be met.

$$\begin{cases} AL^\alpha K^\beta>w(1+r)+B(D) \\ \frac{\partial^2 A(D)}{\partial D^2}L^\alpha K^\beta-\frac{\partial^2 B(D)}{\partial D^2}=0 \end{cases} \qquad (9)$$

If the above two conditions are met, farmers will engage in entrepreneurial activities. Based on the above analysis, this paper proposes hypothesis H1: H1: The use of digital technology by farmers will enable them to gain more income, thereby promoting their choice to engage in entrepreneurship.

3.2 The Impact of Digital Technology on Farmers' Entrepreneurial Choices is Related to Time

The above analysis only focuses on a specific point in time and ignores the element of temporal change. To further enrich the model, this paper introduces the time variable t.

$$Y_f(t)=A\big(D(t)\big)L(t)^\alpha K(t)^\beta- \\ w(t)\big(1+r(t)\big)-B(D(t)) \qquad (10)$$

After introducing the time variable, $L(t)$ and $K(t)$

represent the changes in labor and capital inputs over time, and the wage level forgone by farmers and the corresponding interest rate $r(t)$ also change over time. Meanwhile, $A(D(t))$ and $B(D(t))$ represent, respectively, the changes over time in total factor productivity gains from farmers using digital technology and the increase in learning costs. Accordingly, the above constraints are transformed into the following form:

$$\pi\big(D(t)\big)=\frac{\partial Y_f(t)}{\partial D(t)}-\frac{\partial Y_f(t)}{\partial D(t)}=$$

$$\frac{\partial A(D(t))}{\partial D(t)}L(t)^{\alpha}K(t)^{\beta}-\frac{\partial B(D(t))}{\partial D(t)} \qquad (11)$$

$$\frac{\partial^2 A(D(t))}{\partial D(t)^2}L(t)^{\alpha}K(t)^{\beta}=\frac{\partial^2 B(D(t))}{\partial D(t)^2} \qquad (12)$$

Assume that a farmer's choice to start a business is a long-term behavior. That is, if a farmer chooses to start a business, it is necessary for the farmer to consider that the entrepreneurial income from now until retirement will be greater than the income from choosing to work without starting a business. By incorporating the condition for the maximum income that can be obtained in the second period and summing the farmer's income at each moment of entrepreneurship, that is, by integrating the expression, we obtain the total return to the farmer from starting a business as:

$$\pi_{total}=\int_{t_0}^{t_1}\frac{A\big(D(t)\big)L(t)^{\alpha}K(t)^{\beta}-}{w(t)(1+r(t))-B(D(t))}>0 \qquad (13)$$

Here, t0 is the time when farmers start their entrepreneurial activities, and t1 is the time when farmers retire. π_total represents the possibility that farmers will persist in entrepreneurship if the total future income from their entrepreneurial activities exceeds the total income earned throughout their working life, even if there are temporary losses during some periods. Based on this, this paper proposes hypothesis H2: H2: The impact of digital technology on farmers' entrepreneurial choices is related to time, and the probability of farmers engaging in entrepreneurship varies with changes in the time span.

3.3 Measurement Model
Basic Model
This study refers to Brown [15] to identify moderation effects in multiple regression models and uses secondary moderation effects to examine the impact of digital technology use on farmers' entrepreneurship. If the effect of the independent variable X_1 on the dependent variable Y depends on changes in the independent variable X_2, then X_2 plays a moderating role between X_1 and Y [16]. X2 is called the moderating variable, and X_1 is the focal variable. First, a dummy variable indicating whether the sample is identified as entrepreneurial is used as the dependent variable Y; if the sample is entrepreneurial, it is assigned a value of 1, otherwise Y is assigned 0. A dummy variable indicating whether digital technology is used is taken as the moderating variable X_2; if the sample uses digital technology, it is assigned a value of 1, otherwise 0. Time dummy variables are used as the focal variable X_1, with 2016 defined as the base year and assigned a value of 0. The years 2018, 2020, and 2022 are compared in three separate studies and are assigned a value of 1 accordingly.

The Probit regression model is constructed as follows:

$$P(Y=1|X_1,X_2,Z)$$
$$=\theta(\beta_1 X_1+\beta_2 X_2+\beta_{12}X_1 X_2+\gamma Z) \qquad (14)$$

Here, $\theta(\cdot)$ is the cumulative distribution function of the standard normal distribution, and Z is the control variable. The parameters estimated as β1, β2, and β12 are used to identify the effect of digital technology use on farmers' entrepreneurship. If the estimated parameter β12 is greater than zero, then the moderating effect is positive, indicating that the use of digital technology is beneficial in improving farmers' entrepreneurial levels.

3.4 Endogeneity Test
To avoid potential endogeneity issues in farmers' entrepreneurship, there are a few considerations. First, farmers inclined toward entrepreneurship naturally have a demand for market information and resource exchange, which makes them more willing to engage with digital technology. Second, farmers who are already entrepreneurial often have a relatively solid family background and education, making them inherently more sensitive to digital technology use. This may affect the identification of the impact of digital technology use on farmers' entrepreneurial levels. Considering the correlation between the discrete explanatory variables and the model error term, a simultaneous equation model for digital technology use and farmers' entrepreneurship is constructed as follows:

$$Y^* =\beta_1 X_1+\beta_2 X_2+\beta_{12} X_1 X_2+\gamma Z+$$
$$\varepsilon \quad Y=1[Y^* >0] \qquad (15)$$

$$X^*_2=\alpha Z'+\mu \qquad X_2=1[X^*_2>0] \qquad (16)$$

Among them, ，Z' is an exogenous variable. To ensure the stability of the model, in addition to including control variables, ，Z' also includes the instrumental variable 'average postal and telecommunications expenditure'. If the model has endogeneity, then $E(\varepsilon| X^*_2)\neq0$, that is, $Cov(\varepsilon,\mu)\neq0$. Assume that ε and μ follow a bivariate normal distribution:

$$\begin{pmatrix}\varepsilon\\\mu\end{pmatrix}\sim N_2\left\{\begin{pmatrix}0\\0\end{pmatrix}, \begin{bmatrix}\sigma_1^2 & \rho\sigma_1\sigma_2\\\rho\sigma_1\sigma_2 & \sigma_2^2\end{bmatrix}\right\} \qquad (17)$$

The parameter ρ is the correlation coefficient between the random terms ε and μ. Based on Equation (20), construct the joint log-likelihood function for Equations (18) and (19), with specific reference to the study by Chen Guoqiang [17] and others. The distribution function of a bivariate normal distribution is given as follows:

$$E(Y|X_2)= \theta_2(X^*_2 ,Y^* ,\rho)\big/\theta(X^*_2) \qquad (18)$$

Among them, $\theta2(\cdot)$ is the distribution function that follows a bivariate normal distribution. The parameters of the simultaneous equations are estimated using the Full Information Maximum Likelihood (FIML) method. Based on the joint bivariate Probit distribution of Y and X_2, that is, P （$Y=1$，$X2=1)=\theta_2(X^*_2 ,Y^*,\rho)$, the conditional expected probability of farmers' entrepreneurship, Y, is calculated. The secondary moderating effect of digital technology use on farmers' entrepreneurship, obtained from the nonlinear simultaneous equation model, is expressed as follows: Secondary moderating effect:

$$\varpi(\beta,X)=(\frac{\theta_2\left(X^*_2 ,\beta_1+\beta_2+\beta_{12}+\gamma Z,\rho\right)}{\theta\left(X^*_2 \right)}$$

$$-\frac{\theta_2(X^*_2 ,\beta_1+\beta_2+\gamma Z,\rho)}{\theta(X^*_2)}) \qquad (19)$$

Among them, the secondary moderation effect $\varpi(\beta,X)$ is the difference between the total moderation effect $T(\beta,X)$ and the structural moderation effect $\vartheta(\beta,X)$. Compared with the interaction term β_{12}, the secondary moderation effect plays a true moderating role in promoting farmers' entrepreneurship at the level of digital technology usage. If the secondary effect $\varpi(\beta,X)$ is positive, it indicates that the level of farmers' use of scientific and technological knowledge has a promoting effect on their entrepreneurship. For the sake of simplicity and clarity, this paper no longer presents the regression results for the total and structural moderation effects, instead, the secondary moderation effect is expressed as a nonlinear treatment effect.

4. Explanation of Variables and Descriptive Statistical Analysis of Data

4.1 Sample Selection and Data Processing

The samples in this study are selected from the rural portion of the China Family Panel Studies (CFPS) data, excluding urban samples. Since CFPS data are all year-end data, families that participated in the surveys at the end of 2016, 2018, 2020, and 2022 were selected. Child households (where the oldest family member is under 16 years old) and family samples with missing key variables were excluded. The survey takes the end of 2016 as the baseline, analyzing the changes in the impact of digital technology use on families at the end of 2018, 2020, and 2022, while excluding samples with missing or abnormal values.

4.2 Indicator Selection and Description

4.2.1 Interpreted variables

There are two interpreted variables in this paper, one is from the perspective of families, entrepreneurial activities usually involve a common consultation process among family members, drawing on Guangsu Zhou[8]'s definition of farmers' entrepreneurship in CFPS.And define it with reference to the definitions of farmers' entrepreneurship in CFPS by Bingqi Zhao [18] and Xiaolin Dong [19]. according to the question in the questionnaire "In the past twelve months, have any family members in your family been engaged in self-employment or started a private enterprise?" If the answer is "yes", then the definition of entrepreneurship is assigned to 1, otherwise the assignment value is 0, indicating that it is an entrepreneurial activity.

4.2.2 Core explanatory variables

The core explanatory variable of this paper is the use of digital technology, and this paper examines the relationship between digital technology application and farmers' entrepreneurial decision-making from the dual perspectives of "access" and "use". This paper

uses Ziyu's Liu definition of farmers' digital technology use and makes relevant improvements [20], and conducts a joint evaluation based on the content of the questionnaire "the importance of the Internet to farmers' learning" and "whether to use the Internet". Otherwise, the assignment is 0.

4.2.3 Control variables Generally speaking

The head of the household, as the main speaker of the family, has a direct influence on the entrepreneurial behavior of family members. This article sets the financial respondent of the family as the head of the household, and if there is no financial respondent in the family, the oldest person in the family is the head of the household. The personal and family characteristics of the head of household are mainly considered as control variables, including the age, gender, education level, work, marital status, health status, job security, family care, family economic situation, family borrowing, and the number of family labor force. The descriptive statistical results of each variable are shown in Table 1

4.2.4 Instrumental variables

In order to avoid endogenous problems in the model, this paper refers to the research of Yaoyao Zhang [21], and uses "average household postal and telecommunications expenditure" as an instrumental variable. From the perspective of exogenity, from the survey content of CFPS data, the monthly postal and telecommunications expenses of households mainly refer to the average monthly communication expenses of households for telephones, mobile phones, Internet access and mailing, which is an essential expense for every family, and has almost no impact on major decisions such as family entrepreneurship.

4.3 Descriptive Statistics of Variables

Table 1 presents the characteristics of household heads and basic family information in 2016. From the table, we can roughly observe significant differences in the control variables between entrepreneur households and non-entrepreneur households, indicating that the selection of control variables is effective. Specifically, looking at the mean differences between groups, except for the household head's gender, the household head's ethnicity, the average gender of the family, and whether the family has a pension, which do not show obvious differences between groups, the means of the remaining control variables show significant differences at the 5% or 1% level between entrepreneur and non-entrepreneur households.

Table 1. Basic Characteristics of Household Heads and Families in the Base Year 2016

	Variable Name	Variable Description	All household samples	Aspiring Entrepreneur	Entrepreneur	Test for equality of means between groups	
	Household Head Characteristics	Variable assignment	Mean	Mean	Mean	t-value	p-value
Personal variable	Head of Household Age	Actual survey age of the household head (years)	48.622	48.842	46.531	7.66	0.000
	Head of Household Gender	Actual survey gender of the household head	0.554	0.554	0.559	-0.43	0.663
	Years of Education of Head of Household	Educational years of the household head	5.561	5.425	6.855	-14.2	0.000
	Whether Joined the Youth League	Membership in the Youth League: yes=1, no=0	0.072	0.071	0.083	-1.87	0.060
	Marital Status	Marital status: married=1, not married=0	0.903	0.902	0.914	-1.87	0.061
	Whether Han Ethnicity	Ethnic minority status: yes=0, no=1	0.994	0.994	0.995	-0.86	0.388
	Status	Employment status: employed=1, not employed=0	0.85	0.847	0.873	-3.37	0.001
	Health Status	Health status: unhealthy=0 healthy=1	2.84	2.831	2.923	-3.26	0.001
Family variables	Average age of members	Actual survey age of family members (years)	36.631	36.857	34.47	10.26	0.000
	Average age of members squared	Square of the actual survey age of family members divided by 100	1471.4	1490.471	1289.602	11.19	0.000
	Average gender of household	Male = 1, Female = 0	0.509	0.508	0.511	-0.57	0.565
	Number of household	Actual number of laborers in the	2.704	2.678	2.958	-8.77	0.000

	laborers	family					
	Number of jobs held by household members	Actual number of working people in the family	2.64	2.611	2.918	-9.84	0.000
	Average health level of members	Unhealthy=0 Healthy=1	3.127	3.147	2.937	4.36	0.000
	Whether there is a pension	Has pension = 1; No pension = 0	0.04	0.038	0.059	-3.6796034	0.000
	Average years of education in the household	education and/or number of family members	3.828	3.762	4.451	-10.69	0.000
	Whether there is endowment insurance	Has pension insurance = 1; No pension insurance = 0	0.357	0.357	0.36	-0.24	0.807
	Whether the household has a loan	Has a loan = 1; No loan = 0	0.09	0.082	0.164	-9.97	0.000
	Number of household members	Actual number of family members	4.02	3.962	4.576	-12.04	0.000
	Proportion of children under 15	Proportion of children under 15 in the total family size	1.073	1.044	1.348	-10.001625	0.000
	Proportion of elderly over 65	Proportion of elderly over 65 in the total family size	0.831	0.835	0.792	2.19	0.029
	Eastern region	Eastern region = 1, non-Eastern region = 0	0.245	0.237	0.324	-8.21	0.000
	Central region	Central region = 1, non-Central region = 0	0.263	0.258	0.309	-4.88	0.000
	Western region Average	Western region = 1, non-Western region = 0	0.395	0.406	0.293	10.76	0.000
instrumental variable	Average household postal and telecommunication expenditure	Actual household spending on post and telecommunications	180.234	178.397	197.743	-9.11	0.000

5. Empirical Results and Analysis

5.1 Empirical Results and Analysis of the Basic Model Regression

Rows 3 to 5 of Table 2 present the estimated values of β_1, β_2, and β_{12} under the Probit model. It can be clearly seen from Table 2 that, whether the dependent variable uses the individual-level criterion of working for oneself as entrepreneurship or the household-level criterion of whether there is individual private business activity within the family as entrepreneurship, the coefficient of the interaction term β_{12} is significantly positive. This indicates that, regardless of the time span, the use of digital technology has a positive promoting effect on farmers' entrepreneurial level.

Table 2 provides the estimated coefficients of variables under the Probit model and the values of the nonlinear treatment effects. The degree of impact of digital technology use on farmers' entrepreneurship is determined by the nonlinear treatment effects. From Table 2, except for the household-level nonlinear treatment effect in 2020, which is not evident, the nonlinear treatment effects at both the individual and household levels in other years are significantly positive. In the long term, as the time span increases, the nonlinear treatment effect shows an obvious trend of first low and then high. This suggests that as the time span grows, the promoting effect of digital technology use on farmers' entrepreneurship will become stronger. Hypothesis H1 is thereby validated.

Table 2. Regression Results of the Basic Model

Year	Year2016~2018		Year2016~2020		Year2016~2022	
Dependent Variable	Do any family members run their own business?	Whether working for oneself	Do any family members run their own business?	Whether working for oneself	Do any family members run their own business?	Whether working for oneself
β_1	0.179*** (5.70)	0.094** (1.98)	0.118*** (3.02)	-0.043 (-0.75)	0.234*** (4.95)	0.057 (0.81)
β_2	-0.099 (-1.31)	-0.267** (-2.26)	-0.074 (-0.81)	-0.080 (-0.62)	-0.146 (-1.29)	-0.469** (-2.26)
β_{12}	0.311*** (3.50)	0.321** (2.37)	0.211** (2.16)	0.233* (1.69)	0.284** (2.38)	0.601*** (2.80)
Nonlinear Treatment Effect	0.052* (1.95)	0.020*** (2.64)	0.033 (1.37)	0.016** (1.98)	0.054*** (2.79)	0.027*** (4.75)

Control Variables	Yes	Yes	Yes	Yes	Yes	Yes
Regional Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes

5.2 Endogeneity Test

Regarding the results given by the Probit model, the nonlinear treatment effect at the household level in 2020 was not significant. We use the individual level, specifically whether the person is self-employed, to measure the level of entrepreneurship. Given the joint two-dimensional Probit distribution of Y and X2, further analysis is conducted using the full information maximum likelihood (FIML) method, with the results shown in Table 3. Among them, the coefficients of the interaction terms are significantly positive across the three years, with all three years showing significance at the 1% level, indicating that the use of digital technology has a positive promoting effect on farmers' entrepreneurship.

Table 3. Full Information Maximum Likelihood (FIML) Regression Results

Year	Year2016~2018	Year2016~2020	Year2016~2022
Dependent Variable	Farmers' Entrepreneurial Choice		
β_1	0.179*** (5.70)	0.118*** (3.05)	0.221*** (4.70)
β_2	0.158 (0.93)	0.350* (1.73)	0.284 (1.36)
β_{12}	0.312*** (3.53)	0.215** (2.24)	0.270** (2.31)
ρ	-0.149*** (-1.72)	-0.250** (-2.38)	-0.250** (-2.52)
Nonlinear Treatment Effect	0.070*** (5.22)	0.045*** (5.52)	0.052*** (6.56)
Control Variables	Yes	Yes	Yes
Regional Fixed Effects	Yes	Yes	Yes

Finally, Figure 1 shows the results of the full information maximum likelihood estimation for time spans of 2 years, 4 years, and 6 years in 2018, 2020, and 2022, respectively. According to the information in the figure, as the use of digital technology increases, the probability of farmers starting businesses also rises. As the time span extends, the curve of the impact of digital technology use on farmers' entrepreneurial growth becomes higher. This indicates that over longer time spans, the same level of digital technology use can have a greater promoting effect on farmers' entrepreneurship.
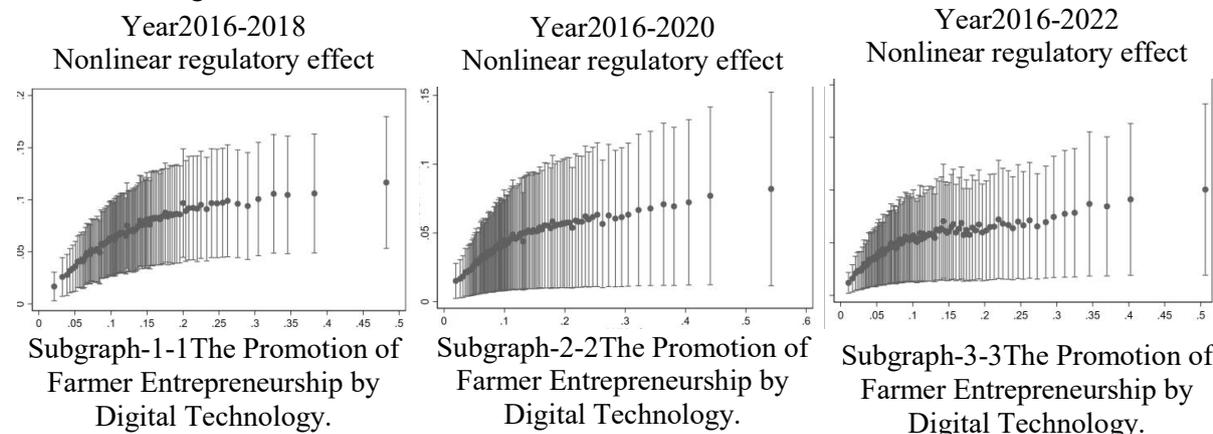
Year2016-2018
Nonlinear regulatory effect

Year2016-2020
Nonlinear regulatory effect

Year2016-2022
Nonlinear regulatory effect

Subgraph-1-1The Promotion of Farmer Entrepreneurship by Digital Technology.

Subgraph-2-2The Promotion of Farmer Entrepreneurship by Digital Technology.

Subgraph-3-3The Promotion of Farmer Entrepreneurship by Digital Technology.

Figure 1. Maximum Likelihood Estimation Results with Complete Information

5.3 Robustness Test

In order to make the results more robust, this paper conducts robustness tests by modifying the sample size, changing the dependent variable, and altering the time span of the study.

5.3.1 Modifying the sample size

Considering that young laborers are the group that uses the internet most extensively, this approach refers toAiping Guan's method [22]. Therefore, laborer samples under 25 years old and over 55 years old are excluded for the robustness test. The study focuses on respondents aged 26–54 as the sample to examine the impact of digital technology on farmers' entrepreneurship. The empirical results are shown in Table 4.

Table 4. Effects of Entrepreneurship on Young and Middle-Aged People

Year	Year2016~2018	Year2016~2020	Year2016~2022
Dependent Variable	Farmers' Entrepreneurial Choice		

β_1	0.150* (2.21)	-0.010 (-0.15)	0.288*** (2.92)
β_2	-0.110 (-0.71)	-0.154 (-1.02)	-0.291 (-1.16)
β_{12}	0.265 (1.50)	0.288* (1.77)	0.406 (1.54)
Nonlinear Treatment Effect	0.023* (1.65)	0.019** (2.15)	0.026** (2.17)
Control Variables	Yes	Yes	Yes
Regional Fixed Effects	Yes	Yes	Yes

From Table 4, it can be seen that the effect of nonlinear processing first decreased from 0.023 in 2018 to 0.019 in 2020, and then increased to 0.026 in 2022 as the span of years extended. The direction of the effect is positive and significant at either the 5% or 10% level, showing a clear trend of first decreasing and then increasing. The results indicate that after changing the sample size, not only does the direction of the effect align with the baseline regression, but the trend is also similar, forming a 'U' shape, demonstrating the robustness of the results.

5.3.2 Replacing the explained variable

The widespread use of digital technology in rural areas has effectively enriched the forms of rural economy. Its role is reflected not only in the decision-making stage of farmers' entrepreneurial and business activities but also in the outcome stage after achieving goals, namely entrepreneurial performance[23]. This study refers to Ziwei Zhou's[24] research on farmers' entrepreneurial choices and selects income from industrial and commercial production and operation after entrepreneurship as the explained variable. If the income from industrial and commercial production and operation exceeds one-fifth of the total household income, the household is considered entrepreneurial and assigned a value of 1; otherwise, it is assigned a value of 0. The empirical results are shown in Table 5.

Table 5. Replacing the Dependent Variable

Year	Year2016~2018	Year2016~2020	Year2016~2022
Dependent Variable	Farmers' Entrepreneurial Choice(Proportion of Operating Income)		
β_1	0.232*** (6.53)	0.163*** (3.93)	0.331*** (7.07)
β_2	-0.214** (-2.37)	-0.178* (-1.74)	-0.045 (-0.41)
β_{12}	0.338*** (3.26)	0.252* (2.32)	0.223** (1.93)
Nonlinear Treatment Effect	0.056*** (3.58)	0.043*** (2.65)	0.050** (2.15)
Control Variables	Yes	Yes	Yes
Regional Fixed Effects	Yes	Yes	Yes

From Table 5, it can be seen that the nonlinear processing effect first decreased from 0.056 in 2018 to 0.043 in 2020, and then increased to 0.050 in 2022 as the time span extended. The direction of the effect is positive and significant at either the 1% or 5% level, also showing a clear trend of first decreasing and then increasing. The results indicate that after changing the sample size, not only does the direction of the impact align with the baseline regression, but the trend of the effect is also similar, forming a 'U' shape, which demonstrates the robustness of the results.

5.3.3 Changing the time span

To further eliminate the impact of specific years and test whether the effect of digital technology usage on farmers' entrepreneurship is stable within the same time span, the periods 2016–2020 and 2018–2022 were chosen for analysis. The results are shown in Table 6:

From the table, it can be seen that whether it is the interaction term β12 from 2016 to 2020 or the interaction term ϕ_{12} from 2018 to 2022, the effect of time on farmers' entrepreneurship is positive and significant at the 10% level. Based on this, this paper can conclude that as the years progress, the interaction effect of digital technology use over time will strengthen.

From the results of the nonlinear treatment effect, the choice of farmers' scientific and technological level has a positive and significant impact on farmers' entrepreneurship. In the same year, the impact of digital technology use on farmers' entrepreneurship will grow larger, indicating that as time goes on, digital technology use will become increasingly important for farmers' entrepreneurship. Hypothesis H2 is thus validated.

To further study the growth of farmers' entrepreneurship under the nonlinear treatment effect at each entrepreneurial probability, we use a full information maximum likelihood (FIML) estimate chart. The empirical results are shown in Figure 2:

Table 6. Robustness Regression Results for Changing Year Span

Year	Year2016~2020	Year	Year2018~2022
Dependent Variable	Farmers' Entrepreneurial Choice	Dependent Variable	Farmers' Entrepreneurial Choice
β_1	0.282*** (5.43)	ϕ_1	0.474*** (8.39)
β_2	-0.234 (-1.57)	ϕ_2	-1.433*** (--5.38)
β_{12}	0.302* (1.95)	ϕ_{12}	0.392* (2.10)
Nonlinear Treatment Effect	0.033** (2.28)	Nonlinear Treatment Effect	0.083** (2.06)
Control Variables	Yes	Yes	Yes
Regional Fixed Effects	Yes	Yes	Yes
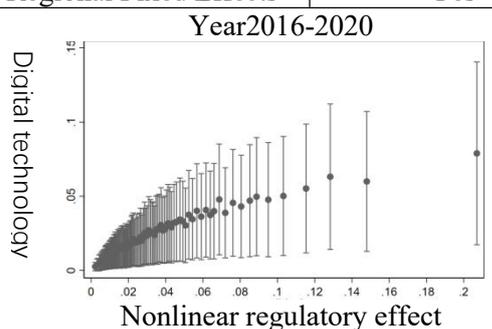
Subgraph-2-1 The Promotion of Farmer Entrepreneurship by Digital Technology.
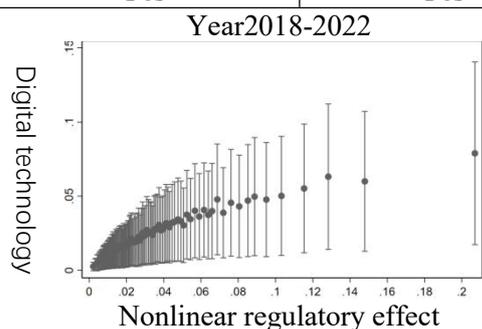
Subgraph-2-2 The Promotion of Farmer Entrepreneurship by Digital Technology.

Figure 2. FIML Robustness Test Analysis Results

It can be observed that the use of digital technology has a significantly positive effect on promoting farmers' entrepreneurship. However, over the same four-year period, there is a noticeable gap between the two in terms of their impact on farmers' entrepreneurial activities, as shown in the figure. From the end of 2016 to the end of 2020, as the level of digital technology usage increased, the probability of entrepreneurship also showed a clear rise. Both digital technology usage and the level of farmers' entrepreneurship exhibited a trend of increasing from zero. By the end of 2022, starting from nearly zero entrepreneurial probability, digital technology usage had already clearly risen above zero. This indicates that even in different years, over the same length of time, the intensity of digital technology's promotion of farmers' entrepreneurship varies significantly, although it remains significantly positive. This validates the findings of the basic regression, demonstrating that digital technology indeed has a positive impact on farmers' entrepreneurial activities, and that this promoting effect continues to strengthen over the years.

6. Conclusions and Implications

6.1 Research Conclusions
First, the use of digital technology has a

significant positive impact on farmers' entrepreneurship. This conclusion remains valid even after testing for endogeneity issues and conducting robustness analyses.

Second, the impact of digital technology on farmers' entrepreneurship varies over different time spans. With the extension of the time span, there is a trend of initially decreasing and then increasing effects.

Third, further analysis shows that the influence of digital technology on farmers' entrepreneurial choices varies among farmers with different levels of non-cognitive abilities. The level of digital technology can significantly enhance non-cognitive abilities, thereby improving farmers' entrepreneurial choices.

6.2 Research Recommendations
Based on the above research conclusions, this paper proposes the following recommendations on how to more accurately and effectively leverage digital technology to guide innovation and entrepreneurship development in rural areas:

First, ensure the accessibility of digital technology to farmers. A digital rural development project should be implemented, vigorously promoting the construction of digital infrastructure. Digital technology should be deeply integrated with rural production and life, and digital rural pilot programs should be

continuously carried out.

Second, build an open entrepreneurial education system led by universities and involving multiple stakeholders from society. Establish digital agriculture platforms to provide intermediary channels for farmers' entrepreneurship. Social organizations and enterprises can participate in rural entrepreneurial services, providing farmers with technical consulting, market information, sales channels, and other support, promoting resource sharing and service integration.

Third, a multi-level digital skills training system should be established to encourage farmers to continuously learn new knowledge and technologies, especially new digital technologies. They should master modern production skills, improve management capabilities, and adapt to changing market demands. Additionally, mobile internet should be effectively utilized as a convenient tool for farmers to access agricultural production information and decision-making support.

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