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How digital skills affect farmers' agricultural entrepreneurship? An explanation from factor availability

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ABSTRACT

Promoting rural household agricultural entrepreneurship is a key way to increase farmers' income and achieve rural revitalization. In the growing digital economy, the ability to use the internet to access information is crucial for agricultural entrepreneurship. Based on the data of China Land Economic Survey, this paper uses the panel Logit fixed-effects model to investigate the impact of digital skills on farmers' agricultural entrepreneurship and the underlying mechanisms. The findings indicate that digital skills have a statistically significant positive influence on farmers' agricultural entrepreneurship. Furthermore, digital skills can enhance farmers' agricultural entrepreneurship by increasing factor availability, including production credit, modern technology, and social capital. The positive effect of digital skills on farmers' agricultural entrepreneurship is more pronounced for farmer groups with more farming experience, greater land resources, no major adversities experienced and lack optimistic expectations for the future. Additionally, this research revealed differences in the impact of different types of digital skills on farmers' agricultural and non-agricultural entrepreneurship. This study contributes to the micro analysis from the perspective of farmers' agricultural entrepreneurship, which provides policy implications for developing countries worldwide to enhance agricultural entrepreneurship by improving digital skills.

Introduction

Numerous studies have indicated that entrepreneurship plays a crucial role in promoting innovation, creating employment opportunities, and fostering economic growth (Yang et al., 2023). Promoting rural household entrepreneurship is not only an important strategy for achieving comprehensive rural revitalization but also a tool for increasing farmers' income (del Olmo-García et al., 2023). Specifically, agricultural entrepreneurship is conducive to enhancing the efficiency of resource allocation in rural areas, fostering the integration of rural industries, and boosting rural economic vitality. Moreover, digital proficiency contributes to elevating rural livelihoods, mitigating poverty, and aligning with the global Sustainable Development Goals (SDGs) on a global scale set by the United Nations (Li et al., 2019). China's Ministry of Agriculture and Rural Development released data showing that by the end of 2022, the cumulative number of entrepreneurs returning to their hometowns to start their own businesses had reached more than 12.2 million, an increase of 8.9 percent year-on-year, and the scale of entrepreneurship had reached a new high. Despite notable progress, challenges persist, including financial constraints and business risks. Thus, understanding and addressing the intrinsic motivations and practical hurdles farmers encounter is crucial to sustaining and amplifying their enthusiasm for entrepreneurship in the digital era.

With the emergence of information technologies such as big data, cloud computing, and artificial intelligence, digital knowledge and information have become critical production factors in the real economy (Gao et al., 2023). The proliferation of digital technologies has triggered both a "diffusion effect" and an "inclusive effect", opening new avenues for rural development (Liu et al., 2022). Remarkably, 55 % of entrepreneurial projects in hometowns utilize information technology to set up online stores, cloud video, live direct marketing, contactless distribution, etc., creating "net red products". A substantial 85 % of these projects integrate primary, secondary, and tertiary industries, spanning production, marketing, and services in agriculture, culture, tourism, and education[1]. The Digital China Development Report (2022) highlights the rapid digitalization of China's agriculture, with the informatization rate of agricultural production

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[1] Last year, more than 10 million people returned to their hometowns to start businesses and innovate. https://www.gov.cn/xinwen/2021-03/25/content_5595514.htm.

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exceeding 25 %. More than 50 % of surveyed farmers reported increased usage of digital technology in agricultural sales, planting and other areas compared to the previous year[2]. Digital technologies have led to the optimal allocation of resources and the emergence of new business models, providing more opportunities for rural entrepreneurship (Bowen & Morris, 2019; Li et al., 2023).

Existing literature exploring the relationship between internet access and rural household entrepreneurship suggests that internet access can enhance social networks, mitigate information asymmetry, and increase access to credit, thereby promoting farmers' entrepreneurship (Tan & Li, 2022). Some literature suggests that people with higher social status are more likely to use the internet for a greater variety of purposes and with better results (Aparo et al., 2022). Omulo and Kumeh (2020) argue that adopting agricultural information and services based on information and communication technology (ICT) can improve agricultural outcomes. Unfortunately, few studies have considered the impact of farmers' digital skills on their agricultural entrepreneurship, and even fewer have analyzed the impact of the mechanisms, despite the many benefits of these skills, such as reducing the cost of information acquisition, easing credit constraints, and enhancing the ability to interface with markets (Li et al., 2023; Barnett et al., 2019).

Therefore, the questions to be answered in this paper are: Questions have emerged in response to the increasing availability of internet access in rural areas: Do digital skills effectively support the growth of agricultural entrepreneurship among farmers? What inherent mechanisms underlie the impact of digital skills on farmers' entrepreneurial pursuits? Are there variations in how digital skills influence agricultural entrepreneurship among different farmers? These questions constitute the core focus of this study, which employs a three-year panel dataset from the China Land Economic Survey to empirically analyze the impact of digital skills on farmers' agricultural entrepreneurship and to uncover its underlying mechanisms.

This study contributes in three key areas: Firstly, it shifts the research focus towards farmers' agricultural entrepreneurship, empirically examining influencing factors using a micro-database and diverse statistical methods for farm households. Secondly, unlike previous studies predominantly centered on Internet use, this research delves into the impact of digital skills, considering varying levels of Internet access to assess their effectiveness on farmers' agricultural entrepreneurship. Thirdly, it underscores the pivotal role of factor availability, emphasizing how digital skills influence the accessibility of production credit, modern technology, and social capital, thereby promoting farmer agricultural entrepreneurship. The study draws on both theoretical models and empirical findings to offer targeted policy recommendations.

The rest of the paper is organized as follows. Section 2 explains the literature review. Section 3 introduces the theoretical analysis and hypotheses development. Section 4 discusses the data sources, variable and empirical models. Section 5 demonstrates the empirical results, including a regression of digital skills on farmers' agricultural entrepreneurship, mechanism test, and heterogeneity analysis. Section 6 is the discussion of findings. Section 7 explores the conclusion and policy implications of this paper.

Literature review

The concept of digital skills

The concept of digital skills constitutes a crucial element of the second "usage gap" within the digital divide. It shares common ground with other notions like digital literacy and competence (Allmann & Blank, 2021). Various frameworks have been proposed by organizations and scholars to assess digital skills from a developmental standpoint. For instance, the United Nations Educational, Scientific and Cultural Organization categorizes digital skills into three groups: 1) basic practical digital skills, 2) generic digital skills, and 3) advanced skills that enabling the transformative use of digital technologies. Another classification by Xiong et al. (2023) identifies operational, formal, information and strategic skills. Described as "basic survival skills for the 21st century" or as a "key asset of the information society" (Li & Hu, 2020), digital skills represent the ability to utilize digital media, encompassing the competencies users employ when learning or working in digital environments (Porat et al., 2018).

The understanding of digital skills varies across different groups (Zhao et al., 2023). From the farmers' standpoint, digital skills encompass the ability to use digital devices like computers and cell phones for retrieving, filtering, creating, evaluating, and sharing digital information. These skills are crucial for integrating digital knowledge into both life learning and agricultural production practices. Notably, digital learning skills, digital financial skills and digital life skills emerge as the three key dimensions, emphasizing the proficiency required to: 1) leverage digital resources for obtaining information on technology, knowledge, policies, and markets; 2) comprehend financial information and secure credit through online platforms; and 3) enhance daily life using tools like smartphones. This underscores the pervasive influence of digital thinking throughout farmers' production and life domains.

Factors influencing agricultural entrepreneurship

Farmer entrepreneurship involves the recombination of resources to exploit opportunities (Fitz-Koch et al., 2018), encompassing both agricultural and non-agricultural entrepreneurship. Within this realm, agricultural entrepreneurship specifically entails entrepreneurial activities within the agricultural sector, predominantly reliant on land as a production factor. This includes the enhancement of agricultural operations and the establishment of new entities like family farms, farmer cooperatives, and social service organizations (Dias, 2019). Distinguished by extended lead times, gradual returns, and heightened vulnerability to external factors such as natural conditions, market dynamics, and unforeseen events, agricultural entrepreneurship stands apart from other entrepreneurial forms (Aldrich & Cliff, 2003).

Based on recent research, the primary influencers of agricultural entrepreneurship can be categorized into two groups: internal and external. Internal factors involve entrepreneurial skills, motivations, resource conditions, passion, and management innovation capabilities (Seuneke et al., 2013; Li et al., 2023). Individuals who are more adept at identifying entrepreneurial opportunities and who have confidence in their skills and abilities are more likely to engage in agricultural entrepreneurship (Arafat et al., 2020). Additionally, Wu and Wu (2023) found a significant in the likelihood of household entrepreneurship with access to credit support. External environmental factors encompass the entrepreneurial environment, social networks, and entrepreneurial ecosystems (Barnes et al., 2015; del Olmo-García et al., 2023). Yang et al. (2023) highlight the pivotal role of the rural entrepreneurial environment, stating that it not only directly impacts the entrepreneurial process but also shapes farmers' cognition, capabilities, and resource accessibility. Romero-Castro et al. (2023) propose that investing in ICT infrastructure is a crucial prerequisite for fostering rural entrepreneurial activities.

Relationship between digital skills and agricultural entrepreneurship

As Internet accessibility expands in rural areas and farmers' digital skills increase, scholars have delved into the impact of digital skills on agricultural production and entrepreneurial behavior (Zang et al.,

[2] Cyberspace Administration of China. Digital China Development Report (2022). http://www.cac.gov.cn/2023-05/22/c_1686402318492248.htm.

2023). Current research primarily explores two key aspects: 1) Proficiency in digital skills proves advantageous for farmers by enabling timely and accurate information collection, reducing the cost of searching for information, and effectively mitigating information asymmetry and financing constraints. This facilitates prompt entrepreneurial activities upon identifying business opportunities (Leng, 2022). Li et al. (2023) reported an 18.5 % increase in farmers' willingness to start agricultural businesses with the adoption of digital technologies. Additionally, farmers can also engage in online procurement of agricultural materials, and conduct online marketing of agricultural products through the Internet (Li et al., 2021). 2) Digital skills are poised to positively influence agricultural performance. The evolution of ICT promotes the scaling up, digitization, and automation of agricultural production. This advancement empowers agricultural operators to implement more precise and scientific field management, reducing the impact of natural disasters and enhancing overall agricultural production efficiency (Khanna & Kaur, 2022; Zhao et al., 2023). Moreover, digital skills play a crucial role in increasing farmers' acceptance of new management concepts, tools, and organizational structures, thereby reshaping traditional smallholder entrepreneurial models.

Literature summary

The existing literature has provided a solid theoretical foundation for this research, but it is incomplete. First, previous work primarily concentrates on the first level of digital divide, but it pays less attention to the influence of higher-level digital skills. Second, how digital skills affect rural household agricultural entrepreneurship has not been elucidated in the existing research. This study aims to address these gaps by examining how digital skills influence agricultural entrepreneurship within rural households through the lens of factor accessibility.

Theoretical analysis and hypothesis development

Direct influence of digital skills on agricultural entrepreneurship

In the realm of neoclassical economics, famers are considered rational. Rural households choose agricultural entrepreneurship when the expected benefits outweigh the expected costs. The objective of agricultural entrepreneurship is to optimize the allocation of labor, land, capital, and other production factors given external market conditions and farmers' own resource endowments. Assessments of optimization are influenced by the information possessed by rural households. Existing research suggests that digital skills can facilitate more comprehensive information searches, which helps refine factor allocation adjustments until optimization is achieved. As a result, digital skills have an incentivizing effect on farmers' agricultural entrepreneurship willingness and behavior (Li et al., 2023), aiding to overcoming disadvantages associated with being geographically distant from urban areas (Kim & Orazem, 2017; Romero-Castro et al., 2023). Fig. 1 illustrates the study's conceptual model.

For rural households, information incompleteness is a fundamental constraint to maximizing utility. According to information search theory, agricultural production decisions are primarily constrained by factors such as production costs and agricultural information. Digital skills can assist rural households in accessing timely agricultural production and market supply-demand information. This access reduces uncertainty caused by information asymmetry and activates the core elements of agricultural entrepreneurship, thus exerting a positive promoting effect on farmers' agricultural entrepreneurship. Moreover, internet platforms can be utilized to disseminate successful entrepreneurship information, production and management information, and government policy information, effectively lowering barriers and reducing risks for rural households with digital skills, thereby enhancing their confidence in entrepreneurship.

Rural households with digital skills can engage in technological innovation in traditional agricultural production methods, promoting processes of scale, digitization, and automation in agricultural production. These advances help farmers optimize resource allocation and improve agricultural productivity, thus providing economic and technological support for agricultural entrepreneurship (Ogutu et al., 2014). Recent studies have shown that the new generation of digital technologies not only increases the probability that farmers will engage in entrepreneurship but also significantly enhances their entrepreneurial performance (Deller et al., 2022). Based on these premises, the first hypothesis is proposed as follows:

Hypothesis 1. Digital skills can promote farmers' agricultural entrepreneurship.

Mechanism of influence

Drawing from Sahlman's theory of resource endowment, essential elements for entrepreneurship include individuals, resources, opportunities, transactional behaviors, and the environment (Sahlman, 1999). Digital skills enhance farmers' access to these elements, thereby influencing their agricultural entrepreneurship. Consequently, this study summarizes the mechanism by which digital skills impact farmers' agricultural entrepreneurship. Improved factor accessibility, including production credit, modern technology, and social capital accessibility promotes farmers' agricultural entrepreneurship.

Credit constraints are a major factor that limits entrepreneurship, including agricultural entrepreneurship (del Olmo-García et al., 2023). Unlike small-scale operations, agricultural entrepreneurship requires economies of scale by expanding operational areas, increasing mechanization, and applying agricultural technology, the goal of

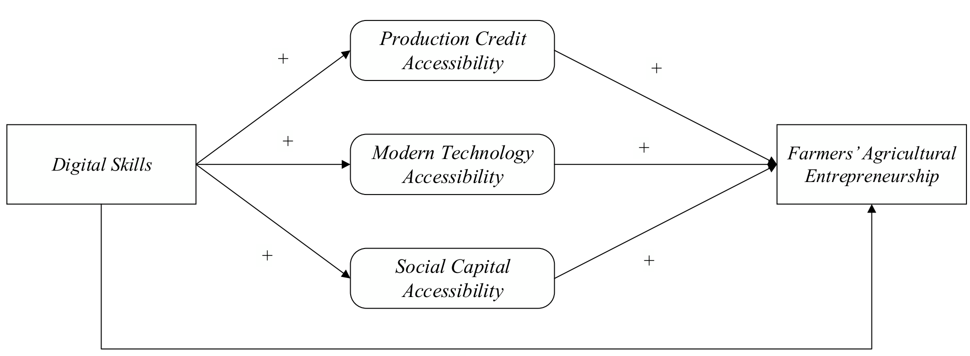

Fig. 1. Analytical framework.

which is the transition from labor-intensive to capital- and technology-intensive processes, all of which require financial support. Digital skills can alleviate credit constraints in agricultural production, positively influencing rural household agricultural entrepreneurship by increasing agricultural credit accessibility.

The lack of collateral and the vulnerability of agricultural production to the natural environmental make it difficult for farmers to obtain loans from financial institutions. Digital skills enable rural households to access financial knowledge through the internet, easing obstacles to credit access that results from inadequate financial literacy. This enables individuals to borrow not only from regional banks but also from digital financial institutions like WeBank (Mao et al., 2023). Digital financial services also offer advantages such as broad coverage and low operating costs; they are better able to meet the capital needs of agricultural entrepreneurs; and they resolve the issue of last-mile in financial services (Wu & Wu, 2023). Additionally, with transactional and other information compiled from rural households' internet usage, financial institutions can better assess applicants' creditworthiness. This enables financial institutions to provide personalized services, thus improving credit support for agricultural entrepreneurship households. Hence, we propose the following hypothesis:

Hypothesis 2. Digital skills can promote farmers' agricultural entrepreneurship by increasing production credit accessibility.

Schultz's theory of the rational peasant suggests that transforming traditional small-scale farming economies hinges on introducing new production factors, inducing the development of modern agriculture. This implies that agricultural entrepreneurs operate at an advanced level of operation. Extensive research indicates the crucial role of technology such as fertilizers, pesticides, genetic improvement, agronomic practices, and precision irrigation (Nam et al., 2017; Chandio et al., 2021) in agricultural production and management (Pan et al., 2018). The technological capability of agricultural entrepreneurs is vital for identifying and exploring entrepreneurial opportunities.

Digital skills facilitate real-time access to information for rural households, enabling them to access information about emergent agricultural technology (e.g., new seed technologies, production techniques), thus supporting development of the agricultural industry (Chandio et al., 2023; Lawin & Tamini, 2019). Evidence suggests that technology like mobile phones and the internet are essential means by which farmers receive agricultural information and news that play a significant role in promoting technological services (Khon et al., 2022). By accessing information about process of agricultural products and farm materials using the internet, farmers can make informed predictions of future price trends, reducing information asymmetry, market risks, and risks associated with agricultural technology adoption, thereby accelerating the adoption of modern technologies (Deng et al., 2019). Specifically, digital skills improve agricultural entrepreneurs' understanding of potential risks and benefits of new technologies in real-time and helps them master their application and operation, thus reducing the risk and uncertainty associated with their adoption. In the context of rural revitalization strategies, digital skills help farmers stay informed about emerging market opportunities that result from the latest policy changes, thereby promoting the adoption of agricultural technologies by small-scale farmers (Zheng et al., 2022). Therefore, we propose the following hypothesis:

Hypothesis 3. Digital skills can promote farmers' agricultural entrepreneurship by increasing modern technology availability.

According to the social embeddedness theory, individuals seeking to maximize their interests maintain good interpersonal relationships due to the long-term benefits derived from social capital. Agricultural entrepreneurs can leverage social relationship networks to obtain targeted resources, including human, technological, and market resources, based on the specific challenges they encounter at different stages of entrepreneurship. These resources play a crucial role in the entrepreneurial process (Radu et al., 2021). As such, the convenient and interactive communication facilitated by digital skills can support entrepreneurial success by helping farmers build and maintain social capital (Barnett et al., 2019).

Digital technology reduces communication barriers imposed by time and distance, helping farmers deepen their social networks. The ability to access information and resources through social networks enables farmers to take advance of more economic opportunities. Social interactions, both online and offline, have significant positive effects on family entrepreneurship choices (Hu et al., 2023). Farmers with digital skills can build communication bridges with distributors, thereby gaining access to market information, technical guidance, and service provision from the supply chain upstream and downstream (Baumüller et al., 2023). Additionally, borrowing from family and friends is another major way by which farmers alleviate entrepreneurial funding constraints. Many entrepreneurial opportunities for farmers also emerge from information and technical guidance provided by family and friends, thus highlighting the importance of social capital. Therefore, we propose the following hypothesis:

Hypothesis 4. Digital skills can promote farmers' agricultural entrepreneurship by increasing social capital availability.

Research design

Data source

This study utilizes data from the China Land Economic Survey conducted by Nanjing Agricultural University from 2020 to 2022. An initial baseline survey was conducted in 2020 followed by tracking surveys in 2021 and 2022, with average tracking rates of 63.8 % and 56.4 %, respectively. Untracked households were supplemented with data from other households in the same villages. The survey adopted a probability-proportional-to-size sampling method, with a total of 26 survey counties randomly selected from 13 prefecture-level cities in Jiangsu Province. Within each county, two townships were randomly chosen, and within each township, one administrative village was selected. In each village, 34 to 64 households were randomly sampled (usually 50 households). The total number of households surveyed across the three phases was 6250. However, due to missing household population and cultivated land information, the final dataset contained 6060 valid observations.

Jiangsu Province, a large agricultural province in China with a well-developed economy and a concentrated population, is traversed by the Qinling Mountains-Huaihe River line, exhibiting common characteristics of agricultural production in the south and north (see Fig. 2). The province has been acknowledged for its advancements in digital technology integration with rural industry. In 2022, there were 14.473 million rural broadband access users in Jiangsu Province, with the development level of digital agriculture and rural areas reaches 67.2 %, and the overall level of agricultural and rural informatization development ranks second in China.[3] Hence, exploring the impact of digital skills on farmers' agricultural entrepreneurship in Jiangsu Province provides valuable insights for understanding agricultural entrepreneurship in China and other developing countries.

Variable setting

Dependent variable

In this study, the dependent variable was farmers' agricultural entrepreneurship (AE). Using relevant scholars' methods of defining agricultural entrepreneurship (He & Li, 2019; Zheng et al., 2020), it

[3] https://www.jiangsu.gov.cn/art/2023/6/21/art_88276_10929404.html.

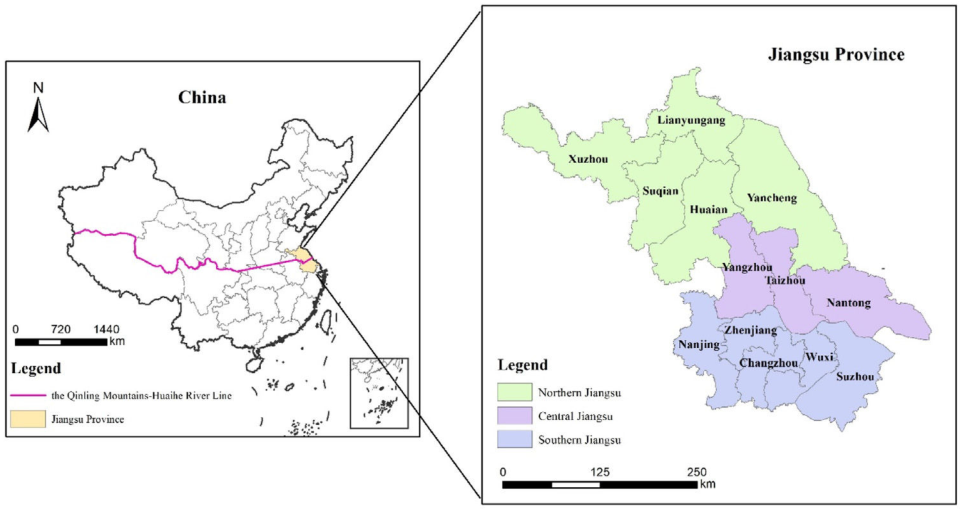

Fig. 2. Location of Jiangsu, China.

was determined based on the actual operational scale and type of entrepreneurial activities undertaken by surveyed households. In terms of economic scale, agricultural entrepreneurship encompasses households engaged in agricultural production with an operational area of at least four times the average cultivated land area per household. Relative measures were replaced by absolute measures to eliminate potential measurement errors caused by differences in resource endowment between individuals and locations. Additionally, large-scale farmers tend to develop into new agricultural business subjects. Agricultural entrepreneurial families belonging to family farms, large-scale professional households, and initiators or core members of farmers' professional cooperatives are included in the scope of agricultural entrepreneurship. Thus, fulfilling the above two conditions is considered as agricultural entrepreneurship. Robustness tests were conducted later in the study based on alternative definitions of agricultural entrepreneurship posed by other scholars.

Independent variable

The explanatory variable in the model was farmers' digital skills (Digit). We assessed farmers' digital skills in terms of digital learning, financial, and life skills (see Table 1), based on Scheerder et al. (2017), Schnebelin ((2022)), and Dabbous et al. (2023). Digital learning skills mainly refer to whether farmers are able to learn technical, policy and legal, current affairs, and financial investment knowledge using the internet. If a farmer can use the Internet to learn any kind of knowledge, then he/she has mastered digital learning abilities, the value is 1; otherwise, the value is 0. Other indicators in this study were calculated in the same way. Digital financial skills refer to whether farmers understand the digital credit of formal financial institutions and the online loan businesses launched by platforms such as Alipay and WeChat. Digital life skills refer to whether farmers purchase insurance for agriculture, healthcare, and elder care online. Considering that these three skills are equally important for farmers' agricultural entrepreneurship, using the number of these three skills mastered by farmers is measured, so the values of digital skills of farmers are 0, 1, 2, 3. Also, digital skills were re-measured using the entropy method for robustness testing.

Table 1
Digital skills indicator system.

Variables	Item
Digital learning skills	Whether or not Internet is used to learn about technology?
	Whether or not Internet is used to learn about policies and laws?
	Whether or not Internet is used to browse for knowledge of current news?
	Whether or not Internet is used to learn about financial investments?
Digital financial skills	Are you aware of the digital credit services offered by formal financial institutions such as banks?
	Are you aware of the online loan business launched by online platforms such as Alipay and WeChat?
Digital life skills	Whether to take out plantation insurance through online?
	Whether to take out a pension insurance policy online?
	Whether to enroll in health insurance online?

Control variables

We selected control variables from three dimensions: household head characteristics, family characteristics, and village characteristics (Ma et al., 2018a; Zheng et al., 2022). Household head characteristics include age, education level, health status, training, and non-agricultural employment. Additionally, the quadratic term of age is included in the model to examine its nonlinear impact on agricultural entrepreneurship. Family characteristics include average age, average education, family burden, labor transfer distance, party member, physical capital, productive assets, and facility agriculture, of which agricultural labor transfer distance is weighted by the distance of family labor force working outside. The weights of the proportion of labor force transferring within townships, counties, provinces, and outside provinces are 1, 2, 3, and 4, respectively. Village characteristics indicate whether the village has rural industries.

Descriptive statistical analysis

Table 2 presents the descriptive statistics for the main variables. The mean value of AE is 0.0325, and the standard deviation is 0.1774. This means that farmers' agricultural entrepreneurship accounts for only 3.25 % of the total survey sample. The proportion of farmers' agricultural entrepreneurship is relatively low. The mean value of digital skills 0.4909, and the standard deviation is 0.7443. This indicates that the level of digital skills acquired by the sample farmers is relatively low and significantly different. Further, we found that the percentage of farmers who mastered one of the digital skills was 35.97 %, which is a higher result than the 14.5 % of farmers using the Internet to access agricultural information (Zheng et al., 2022).

Methods

Basic models

Due to the binary nature of the dependent variable in this study, we selected the panel Logit model to avoid the heteroscedasticity problem caused by the linear probability model. A normality test

Table 2
Definition and descriptive statistics of variables.

Variables	Meaning and assignment of variables	Mean	S.D.
Dependent variable			
AE	Classified as an agricultural entrepreneurial household?1=Yes; 0=No	0.0325	0.1774
Independent variable			
Digit	Combined level of digital skills, defined as the number of digital learning skills, digital financial skills and digital life skills mastered	0.4909	0.7443
Control variables			
Gender	Male = 1; Female = 0	0.9211	0.2696
Age	Actual age of the farmer, unit: years	62.9746	10.2299
Age²	Square of age divided by 100	40.7043	12.4759
Education	Years of education of farmer, unit: years	7.2096	3.6734
Health	Very poor = 1, Poor = 2, Fair = 3, Good = 4, Very good = 5	3.9421	1.1010
Training	Participation in agricultural training? Yes=1, No=0	0.3178	0.4657
Non-agricultural employment	Annual nonfarm employment time share	0.2196	0.3359
Average age	Average age, unit: years	50.5801	13.2622
Average Education	Average years of schooling, unit: years	7.3111	2.8202
Family burden	(Number of elderly persons and minors in the household)/Total number of persons in the household	0.2889	0.2888
Labor transfer distance	Weighted treatment of distance to work outside the farm	0.6778	0.5967
Party member	If the household includes one or more party members, Yes =1, No =0	0.3040	0.4600
Physical capital	Does the household have any property other than a homestead dwelling? Yes=1, No=0	0.2946	0.4559
Productive assets	Does the household own agricultural equipment? Yes=1, No=0	0.1467	0.3538
Facility Agriculture	Area of family-run facility agriculture, units: acres (plus 1 to facilitate logarithmic transformation)	0.0736	0.4233
Featured Industries	Does the village have rural industries? Yes=1, No=0	0.2071	0.4053

revealed that the variables did not follow a normal distribution, validating our choice of the panel Logit model. Regression results report the marginal effects obtained from the Logit model.

$$AE_{it}^* = \beta_0 + \beta_1 Digital_{it} + \sum \beta_k Controls_{it} + Area_i + Year_t + \varepsilon_{it} \quad (1)$$

$$AE_{it} = 1(AE_{it}^* > 0) \quad (2)$$

In model (1) and model (2), subscripts i and t represent farmer and year, respectively. AE_{it}represents farmers' agricultural entrepreneurship, AE_{it}^* denotes latent variable, if $AE_{it}^* > 0$, then AE_{it} takes the value 1, otherwise 0. $Digital_{it}$ indicates whether the respondent possessed digital skills. $Controls_{it}$ indicates control variables, including individual-, household-, and village-level variables. $Area_i$ and $Year_t$ denote region and year fixed effects, respectively, to control for geo-environmental differences in agricultural entrepreneurship and time trends in behavior. ε_{it} are residual values; β_0, β_1 and β_k are the coefficients to be estimated, and when the model β_1 is significant, it means that digital skills have a significant aggregate effect on farmers' agricultural entrepreneurship.

Mediation model

Further, to test whether factor availability acts as a mechanism through which digital skills facilitate farmers' AE, we adopt the specific model as follows:

$$Factor_{it} = \beta_0 + \beta_2 Digital_{it} + \sum \beta_k Controls_{it} + Area_i + Year_t + \varepsilon_{it} \quad (3)$$

$$AE_{it} = \beta_0 + \beta_3 Digital_{it} + \beta_4 Factor_{it} + \sum \beta_k Controls_{it} + Area_i + Year_t + \varepsilon_{it} \quad (4)$$

We test the effectiveness of the availability of factor (*Factor*) as the intermediary factor using the stepwise method (Baron & Kenny, 1986), which include access to production credit, modern technology, and social capital. Model (3) and (4) were constructed on the basis of model (1) to test the mediating effect of factor availability. In model (1), β_1 is the effect of digital skills on AE without considering factor availability. In model (3), β_2 is the effect of digital skills on factor availability. In model (4), β_4 is the impact of factor availability on AE, and β_3 is the impact of digital skills on AE considering factor availability.

Specifically, the test procedure for mediating effects is as follows: First, test Model (1). If β_1 is not significant, the mediation effect test is terminated. However, if β_1 is significant, test models (3) and (4) in turn. Second, if β_2 and β_4 are both significant, then the intermediation effect is significant. In this context, if β_3 is significant, factor availability has a partial mediating effect. However, if one of β_2 and β_4 is not significant, the sobel test needs to be applied. If the result is significant, it indicates that there is a mediating effect; conversely, it indicates that there is no mediating effect.

Empirical results and discussion

Baseline regression result

Table 3 presents the baseline estimation results. Column (1) displays the result of the regression excluding the control variables and shows that marginal coefficient of digital skills on farmers' AE is 0.0259. Column (2) and (3) show the regression results when control variables are added stepwise. The treatment effect of digital skills decreased as the control variable increased, but the coefficient on digital skills remained significantly positive at the 1 % level. As shown in column (3), the marginal coefficient for Digit is 0.0110, which indicates that each unit increase in digital skills increases the probability of farmers' AE by 1.10 percentage points. Based on these findings, Hypothesis 1 is validated, which states that digital skills have a positive and significant effect on farmers' AE.

This is because, firstly, as studied by Li et al. (2023), access to the Internet allows farmers to sell surplus produce over the Internet, which increases their willingness to expand agricultural production. Secondly, information is crucial for entrepreneurial success (Shane et al., 2000), and farmers can access more agricultural production information, including production techniques, market trends, and industry policies, via the internet. This greatly expands their information channels, reduces information search costs, and alleviates information barriers (Aker, 2011). In addition, a lack of capital is a major constraint to farmers' entrepreneurship (Liu et al., 2022). Farmers with digital skills can access finance through a variety of channels, thereby alleviating the financing constraints faced by entrepreneurship. Finally, the internet facilitates the dissemination of information about advanced technologies and the latest policies. By mastering digital skills, farmers can enhance their technological awareness and management skills in agricultural production, thereby increasing the

Table 3
Digital skills and agricultural entrepreneurship.

Variables	(1)	(2)	(3)
Digit	0.0259*** (0.0031)	0.0145*** (0.0029)	0.0110*** (0.0028)
Gender		0.0149 (0.0118)	0.0065 (0.0103)
Age		0.0046** (0.0023)	0.0042** (0.0021)
Age²		−0.0070*** (0.0023)	−0.0057*** (0.0021)
Education		−0.0015* (0.0008)	−0.0024*** (0.0009)
Health		0.0052* (0.0028)	0.0014 (0.0026)
Training		0.0427*** (0.0055)	0.0328*** (0.0048)
Non-agricultural proportion		−0.0761*** (0.0111)	−0.0425*** (0.0099)
Average age			−0.0006** (0.0003)
Average Education			0.0025* (0.0013)
Family burden			0.0052 (0.0130)
Agricultural labor transfer distance			−0.0191*** (0.0057)
Party member			−0.0088 (0.0055)
Physical capital			0.0188*** (0.0055)
Productive assets			0.0417*** (0.0050)
Facility Agriculture			0.0072*** (0.0026)
Featured Industries			0.0124*** (0.0046)
Region fixed effect	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes
Wald	152.91***	341.21***	430.34***
Pseudo R^2	0.0740	0.2837	0.3896
Observations	6060	6060	6060

Note: Marginal effects are reported in the table, and standard errors are shown in brackets. ***, ** and * indicate significance at 1, 5 and 10 % levels, respectively.

capacity of agricultural production and management and the sustainability of agricultural entrepreneurship (Kaila & Tarp, 2019; Zheng et al., 2022).

Robustness checks

To examine the robustness of the effect of digital skills in promoting farmers' AE, this study employs the following three methods for robustness tests.

Variable replacement

Firstly, with reference to Wang et al. (2023), the core explanatory variable of digital skills was recalculated using the entropy method, where farmers' digital skills were valued as a number within the range of [0,1]. Secondly, different measures were also used to assess agricultural entrepreneurship: 1) whether the area of land transfer-in exceeded 10 mu; 2) whether a household was engaged in agricultural entrepreneurship; and 3) whether a household had an actual operating area of at least three times the average arable land area and was involved in agricultural entrepreneurship (Li & Qian, 2022). In Table 4, column (1) ~ (4) reveal that the coefficient of digital skills remains significantly positive. The robustness test results after variable replacement are in line with the main findings, affirming the robustness of the research outcomes.

Sample replacement

As some farmers are primarily involved in non-agricultural employment or non-agricultural entrepreneurship, their households have essentially ceased agricultural production. Although this group generally exhibits higher internet proficiency, their practical applications vary significantly. We removed samples of farmers with zero operating area, thereby focusing on the impact of digital skills on farmers' AE who are in actuality engaged in agricultural production. The results in Column (5) of Table 4 indicate that the marginal effect coefficient of digital skills is 0.0181, passing the significance test at the 1 % level, and the coefficient slightly higher than the results presented in Table 3. Therefore, changing the sample does not affect the main findings.

Model replacement

Based on the results in Table 2, the portion of surveyed farmers engaged in agricultural entrepreneurship is only 3.25 %, representing a relatively rare event with low occurrence probability. Following the approach of King and Zeng (2001), we performed corrections on the results by utilizing the Complementary log-log model. As shown in Column (6) of Table 4, the estimated marginal effect is close to the Logit model results presented in Table 3, indicating that there is no severe rare event bias issue. Hence, regardless of the method used to evaluate robustness, it can be confirmed that digital skills promote

Table 4
Robustness checks.

Variables	(1) Independent variable replacement	(2)	(3) Dependent variable replacement	(4)	(5) Sample size replacement	(6) Model replacement
Digit		0.0100* (0.0048)	0.0129*** (0.0034)	0.0109*** (0.0029)	0.0181*** (0.0044)	0.0094*** (0.0026)
Digit2	0.0489*** (0.0164)					
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Region fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Wald	420.00***	667.67***	427.39***	445.86***	377.37***	596.21***
Pseudo R^2	0.3839	0.3154	0.3099	0.3835	0.3845	—
Observations	6060	6060	6060	6060	3819	6060

Note: Marginal effects are reported in the table, and standard errors are shown in brackets. ***, **and * indicate significance at 1, 5 and 10 % levels, respectively.

farmers' AE, validating the reliability of the baseline regression conclusions.

Endogeneity test

While previous empirical results confirm that digital skills promote farmers' AE, reverse causality or sample selection bias could disturb the findings of this study. On the one hand, farmers need to acquire more knowledge and skills for agricultural entrepreneurship, and the internet is the key channel through which farmers can access relevant information. On the other hand, due to the limitations of the research design, there may be factors that not only affect digital skills but also affect farmers' AE. To address these two types of issues, we used instrumental variable method and propensity score matching (PSM) for endogeneity analysis.

Instrumental variables method

Both relevance and exogeneity requirements need to be satisfied in the selection of instrumental variables. The internet penetration rate of other households at the village level, excluding the targeted household, was chosen as the instrumental variable for digital skills (Deng et al., 2019). According to the theory of peer effects, peer behavior is an important determinant of individual behavior (Ma et al., 2018b). On the one hand, neighbors, relatives, and even local internet usage trends can affect internet use in sampled households. Internet penetration rate, as the infrastructure of digital skills, is closely linked to farmers' digital skills. On the other hand, internet penetration rate belongs to a variable at the regional level, which does not affect AE at the micro level. That is, the internet penetration rate, as an instrumental variable of digital skills, fully satisfies the conditions of relevance and exogeneity of instrumental variables. Considering that AE is a binary variable, an extended regression model framework with the Xteprobit model was used to handle such endogeneity issues. This model can simultaneously address the endogeneity of explanatory variables, the non-random allocation of policy variables in the effect, and sample selection issues. The Probit model results were also used for comparison, and the results are presented in Table 5.

Column (1) in Table 5 shows the marginal effects of the panel Probit model. Digital skills have a significant positive impact on farmers' AE, and the marginal effects are similar to the results of the Logit model, further confirming the robustness of the baseline regression. Column (2) shows that the instrumental variables have a significant positive impact on digital skills, indicating that the instrumental variables satisfy the relevance assumption. Column (3) shows that the coefficient of the residual term is significant at the 1 % level, reflecting the reliability of the instrumental variable estimation results. After addressing endogeneity issues, digital skills still have a significant positive impact on farmers' AE, increasing the probability of agricultural entrepreneurship by 1.07 %, which is close to the baseline results. Based on these findings, Hypothesis 1 is further validated.

Table 5
Endogeneity test.

Variables	(1) Probit	(2) First Stage *Digit*	(3) Second Stage *AE*
Digit	0.0121*** (0.0026)		0.0107*** (0.0085)
IV		0.0621*** (0.0194)	
Control variables	Yes	Yes	Yes
Region fixed effect	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes
Wald	381.73***		454.02***
corr (e.*Digit*, e.*AE*)	—	—	−0.7613*** (0.0731)
corr (*Digit*[id], *AE*[id])	—	—	−0.6018*** (0.1105)
Pseudo R^2	0.3940	—	—
N	6060	6060	6060

Note: Marginal effects are reported in the table, and standard errors are shown in brackets. ***, ** and * indicate significance at 1, 5 and 10 % levels, respectively.

Table 6
PSM results.

Matching method	(1) Nearest neighbor matching	(2) Kernel matching	(3) Caliper matching
Process group	0.0676	0.0676	0.0676
Control group	0.0124	0.0124	0.0124
ATT	0.0335***	0.0317***	0.0327**
N	6060	6060	6060

Note: *** and ** indicate significance at 1 % and 5 % levels, respectively.

PSM method

Sample selection bias is an important contributor to endogeneity in estimation results. Following the approach of Zhang et al. (2022), PSM was used to construct a "counterfactual" framework for the impact analysis of digital skills on farmers' AE. This framework was used to test and correct the robustness of the previous regression results and to minimize sample selection bias. Digital skills were transformed into a binary variable.

The regression results in Table 6 show that the average treatment effect (ATT) indicates that digital skills can promote farmers' AE. Compared with the control group, the probability of farmers' AE increases by 3.35 %, 3.17 %, and 3.27 %, respectively, under 1:5 nearest neighbor matching, kernel matching, and caliper matching, respectively. These results are similar to the baseline regression results, indicating that the impact of digital skills on farmers' AE is significant, even after taking sample selection bias into account.

Mechanism

To test the impact mechanism of digital skills on farmers' AE, this paper selects factor availability as the mediating variable, including production credit accessibility (*PCA*), modern technology accessibility (*MTA*), and social capital accessibility (*SCA*). PCA indicates whether farmers obtain production loans; MTA is measured by the number of applied modern technologies, including improved seed services, soil testing and formula technology, pest and disease control technology, or energy-efficient agricultural facilities technology, with a higher number indicating the adoption of a higher number of technologies; SCA indicates the number of people from whom a farmer can borrow 50 thousand RMB when facing difficulties.

PCA mechanism

Table 7 shows the mediating effects of PCA. Columns (1) ∼ (4) show that digital skills and PCA have a positive effect on AE at a significance level of 1 %, whether control variables are included or not. This suggests that digital skills significantly increase farmers' access to production credit, facilitating their ability to obtain credit funds, and that the mediating effect of PCA is significant. That is, digital skills can promote farmers' AE by mediating increased PCA, following the path *digital skills* → *PCA*→ *farmers' AE*. These findings are consistent with those of Li et al. (2023). Financial constraints are significant factors that limit farmers' AE, and credit support is a means by which these constraints can be overcome. Acquiring digital skills helps farmers access financing information from formal financial institutions and internet finance platforms, increasing the likelihood of obtaining credit support. Thus, Hypothesis 2 is supported by the study findings.

Table 7
Tests on the mediating effects of PCA.

Variables	(1) PCA	(2) PCA	(3) AE	(4) AE
Digit	0.0374***	0.0197***	0.0177***	0.0086***
	(0.0039)	(0.0040)	(0.0026)	(0.0027)
PCA			0.0786***	0.0409***
			(0.0060)	(0.0044)
Control variables	No	Yes	No	Yes
Region fixed effect	No	Yes	No	Yes
Year fixed effect	No	Yes	No	Yes
Wald	169.57***	444.42***	429.57***	428.15***
Pseudo R^2	0.0609	0.2271	0.2534	0.4508
Observations	6060	6060	6060	6060

Note: Marginal effects are reported in the table, and standard errors are shown in brackets. ***, ** and * indicate significance at 1, 5 and 10 % levels, respectively.

Table 8
Tests on the mediating effects of MTA.

Variables	(1) MTA	(2) MTA	(3) AE	(4) AE
Digit	0.3622***	0.1926***	0.0193***	0.0104***
	(0.0293)	(0.0261)	(0.0029)	(0.0028)
MTA			0.0117***	0.0031**
			(0.0014)	(0.0013)
Control variables	No	Yes	No	Yes
Region fixed effect	No	Yes	No	Yes
Year fixed effect	No	Yes	No	Yes
Wald	—	—	269.81***	427.11***
F	38.45***	45.79***	—	—
Pseudo R^2/R-squared	0.0607	0.2505	0.1249	0.3931
Observations	6060	6060	6060	6060

Note: Marginal effects are reported in columns (3) and (4) of the table, and standard errors are shown in brackets. ***, ** and * indicate significance at 1, 5 and 10 % levels, respectively.

MTA mechanism

Table 8 shows the mediating effects of MTA. Columns (1) and (2) show that digital skills have a positive impact on MAT. Furthermore, column (3) and (4) show that both digital skills and MTA have positive coefficients at significance levels of 1 % and 5 %, respectively. This suggests that digital skills increase farmers' MTA, and that improved MTA significantly enhances the probability of farmers' AE. Therefore, the mediating effect of MTA is significant. That is, the mechanism of MTA follows the path: *digital skills → MTA → farmers' AE*. Applying modern technology in farming helps reduce production costs and improve operational efficiency. At the same time, digital skills can compensate for farmers' cognitive biases towards modern technology. A higher level of MTA not only indicates their willingness to take risks but also demonstrates their agricultural production skills, both of which are advantageous for farmers' AE (Kangogo et al., 2021). Based on these findings, Hypothesis 3 is supported.

SCA mechanism

Table 9 shows the mediating effects of SCA. Columns (1) and (2) show that digital skills have a positive impact on SCA, indicating that digital skills can enhance farmers' access to social capital. Moreover, column (3) and (4) show that both digital skills and SCA have significant positive impacts on farmers' AE. This indicates that digital skills can increase SCA, and improved SCA significantly enhances the probability of farmers' AE. Thus, the SCA mechanism follows the path: *digital skills → SCA→ farmers' AE*. Entrepreneurial behavior is closely related to an individual's social relationships. As demonstrated by recent work (Barnett et al., 2019; Hu et al., 2023), the use of information and communication technology expands an individual's social network, which facilitates the identification of potential

Table 9
Tests on the mediating effects of SCA.

Variables	(3) SCA	(4) SCA	(5) AE	(6) AE
Digit	3.8429***	2.2225***	0.0251***	0.0109***
	(0.4569)	(0.3500)	(0.0031)	(0.0028)
SCA			0.0002***	0.0001**
			(0.0001)	(0.0001)
Control variables	No	Yes	No	Yes
Region fixed effect	No	Yes	No	Yes
Year fixed effect	No	Yes	No	Yes
Wald	—	—	157.90***	436.36***
F	15.08***	9.27***	—	—
Pseudo R^2/R-squared	0.0222	0.0620	0.0846	0.3911
Observations	5941	5941	5941	5941

Note: Marginal effects are reported in columns (3) and (4) of the table, and standard errors are shown in brackets. ***, ** and * indicate significance at 1, 5 and 10 % levels, respectively.

entrepreneurial opportunities and access to funding support. A significant proportion of sampled agricultural operators were influenced by their relatives and friends in their decision to engage in agricultural entrepreneurship. Farmers also received information, technology, and financial support from their peers when facing operational difficulties. Therefore, Hypothesis 4 is supported.

Heterogeneity analysis

Within the theoretical framework, the combination of family support and digital skills application is advantageous for individual entrepreneurship (Soluk et al., 2021). This study employed a heterogeneity test based on the family's resource conditions and development status. In addition, heterogeneity of the impact of different types of digital skills on agricultural and non-agricultural entrepreneurship was analyzed with respect to variability among the different types of digital skills.

Heterogeneity in resource conditions: farming experience and cultivated land quantity

The study examines agricultural entrepreneurial decisions when facing different resource conditions, particularly whether farmers have entrepreneurial experience and the characteristics necessary for entrepreneurship. Farming experience and the cultivated land area reflect resource conditions; thus, this study primarily measured rural family resource conditions from two perspectives and conducted heterogeneity analysis.

On the one hand, agricultural entrepreneurship often results from family joint decision-making, and entrepreneurial behavior is related to early-life experience of decision-makers (Chen et al., 2023) . In this study, individual farming experience was determined based on whether the household head frequently engaged in agricultural activities before the age of 16 (Yang & Ji, 2022). The results in columns (1) and (2) of Table 10 show that digital skills have positive impacts on farmers' AE who had farming experience before the age of 16. However, the influence on farmers' AE who did not engage in farming activities frequently before the age of 16 was not significant. This indicates that digital skills can promote farmers' AE with more farming experience.

On the other hand, land availability is closely related to agricultural scale expansion (Stenholm & Hytti, 2014). Therefore, self-owned land resources have positive impacts on farmers' choice of agricultural entrepreneurship. In this study, family basics are measured by the area of self-owned contracted land and are specifically divided into two groups based on whether the area exceeds the sample mean. The results in columns (3) and (4) of Table 10 show that digital skills have a significant positive impact on farmers' AE with smaller and larger areas of self-owned contracted land. However, the impact

Table 10
Heterogeneity of household resource conditions.

Variables	(1) Non-experienced	(2) Experienced	(3) Below average	(4) Above average
Digit	0.0101	0.0108***	0.0104***	0.0154**
	(0.0055)	(0.0030)	(0.0028)	(0.0073)
Control variables	Yes	Yes	Yes	Yes
Region fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Wald	128.32***	322.01***	276.32***	192.59***
Pseudo R^2	0.4010	0.4044	0.4374	0.3323
Observations	1268	4792	4486	1574

Note: Marginal effects are reported in the table, and standard errors are shown in brackets. ***, ** and * indicate significance at 1, 5 and 10 % levels, respectively.

on farmers' AE with larger areas of self-owned contracted land is more significant.

It is evident that the better the resource conditions of farmers' families, the more digital skills can promote AE. This also confirms that areas and farmers with relatively poor agricultural resource conditions are more likely to engage in non-agricultural employment or entrepreneurship.

Heterogeneity in development status: major adversities and future expectations

In addition to family resource conditions, the development status of rural households, whether households have experienced major adverse events, and their expectations for future conditions influences farmers' decisions regarding agricultural entrepreneurship (Yao & Li, 2023). To understand the impact of digital skills on farmers' AE in different family circumstances, we assessed rural family development status from two perspectives: positive and negative.

Major adverse events, such as illness, death and natural disasters, can damage family assets and property, leading to decrease in income and consumption, and exacerbating family vulnerability, thereby influencing influence farmers' entrepreneurial decisions (Pham et al., 2021; Li et al., 2023). Consequently, this study categorized households based on whether they had experienced major adverse events and analyzes heterogeneity for both groups. The empirical results in columns (1) and (2) of Table 11 indicate that digital skills don't have a significantly impact on farmers' AE that have experienced major adverse events. This may be because adverse events place rural families in difficult circumstances, diminishing the resources and energy that would allow them to engage in entrepreneurial activities in the short term.

Entrepreneurship itself is a high-risk economic activity, and financial stability increases the chances of entrepreneurial success. Therefore, this study employed responses indicating household attitudes toward future income growth in the next 1–2 years (pessimistic, moderate, or optimistic) to group households and analyze the heterogeneity of the impact of digital skills on agricultural entrepreneurship among different groups. The results in columns (3), (4), and (5) of Table 11 indicate that digital skills have a significantly positive impact on farmers' AE with pessimistic and moderate expectations for future income growth. The effect of digital skills on farmers with optimistic future income expectations is not significant. This may be because Chinese smallholder farmers are highly resilient and tend to return to reliance on agricultural production when external income is not expected to be high, aiming to compensate for the loss of "de-farming" through "re-agriculturalization". Li et al. (2022) found that, with the joint support of the State and society, Chinese smallholder farmers tended toward "re-agriculturalization" during the COVID-19 pandemic, reflecting livelihood resilience characteristics.

Digital skills have a positive impact on farmers' AE whose households have not experienced significant adverse impacts and who lack positive expectations of future income.

Further analysis: differences in the impact of digital skills and type of entrepreneurship

Based on the definition of digital skills provided earlier, we categorized digital skills into three types: digital learning, financial, and life skills. We analyzed heterogeneity in the impact of these three types of digital skills on farmers' AE. Building on the analysis of the impact of digital skills on agricultural entrepreneurship, we further explored the influence of digital skills on farmers' non-agricultural entrepreneurship. Specifically, we used farmer engagement in industrial or industry to determine whether they were involved in non-agricultural entrepreneurship.

According to the results in Table 12, digital skills not only increase the likelihood of farmers' agricultural entrepreneurship but also enhance the probability of non-agricultural entrepreneurship. However, the impact on farmers' non-agricultural entrepreneurship is more significant. Additionally, the effects of different types of digital skills have different effects on different types of entrepreneurial activities. Digital learning and financial skills have significant positive impacts on both agricultural entrepreneurship and non-farm entrepreneurship, with digital learning skills having a greater impact on

Table 11
Heterogeneity of family development status.

Variables	(1) Encounter	(2) Non-encounter	(3) Pessimistic	(4) Medium	(5) Optimistic
Digit	0.0113	0.0106***	0.0123**	0.0132***	0.0068
	(0.0080)	(0.0028)	(0.0050)	(0.0035)	(0.0051)
Control variables	Yes	Yes	Yes	Yes	Yes
Region fixed effect	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes
Wald	86.02***	369.09***	94.34***	169.83***	179.71***
Pseudo R^2	0.3415	0.4115	0.4104	0.4114	0.4362
Observations	850	5210	1097	2596	2131

Note: Marginal effects are reported in the table, and standard errors are shown in brackets. ***, ** and * indicate significance at 1, 5 and 10 % levels, respectively. Due to the fact that some farmers did not answer this question, the total sample size for the heterogeneity analysis of future expectations was 5824.

Table 12
Heterogeneity in the impact of different digital skills and different types of entrepreneurships.

Variables	(1) *Digit*	(2) *Digital learning skills*	(3) *Digital financial skills*	(4) *Digital life skills*
Agricultural Entrepreneurship	0.0110***	0.0165***	0.0134**	0.0066
	(0.0028)	(0.0048)	(0.0092)	(0.0062)
Non-agricultural Entrepreneurship	0.0121***	0.0129*	0.0222***	0.0095
	(0.0041)	(0.0071)	(0.0075)	(0.0081)

Note: Marginal effects are reported in the table, and standard errors are shown in brackets. ***, ** and * indicate significance at 1, 5 and 10 % levels, respectively.

agricultural entrepreneurship and digital financial skills having a greater impact on non-farm entrepreneurship. Digital life skills have a non-significant impact on both agricultural entrepreneurship and non-farm entrepreneurship.

This may be due to the Chinese government's consistent emphasis on rural revitalization, frequently covered in current affairs news, which has increased exposure to rural entrepreneurship prospects. Access to technical knowledge through the internet has improved agricultural production capacity, so digital learning skills have had a large impact on farmers' agricultural entrepreneurship. In contrast, farmers' non-agricultural entrepreneurship may be stymied by financial constraints. Digital learning skills may be more useful for easing financial constraints, thereby increasing farmers' likelihood of engaging in non-agricultural entrepreneurship. In addition, digital life skills may be passively accepted due to promotion by higher levels of government or the market. For example, village cadres go door-to-door to coach farmers about how to make online insurance payments, and many farmers are paid online by village cadres, relatives, or neighbors on their behalf; many farmers have not yet fully mastered digital life skills, and thus the impact on farmers' entrepreneurship is not significant.

Discussion

Our empirical findings underscore the role of digital skills in fostering farmers' agricultural entrepreneurship, which coincides with the assertion that digital skills can alleviate information inequality and improve agricultural management (Li et al., 2023). In contrast to prior studies overly fixated on Internet access tiers (Barnett et al., 2019), our focus extends to the impact of Internet use behavior and extent on farmers' agricultural production decisions. Recognizing the digital divide encompasses multiple levels, including not just access but also in internet usage and derived benefits (Scheerder et al., 2017; Song et al., 2020), we expand the system of indicators for digital skills, drawing on Bowen and Morris (2019), work highlighting the link between the digital gap and agricultural entrepreneurship. Deller et al. (2022) provide evidence of the positive impact of broadband speed on rural entrepreneurship. Collectively, these insights suggest that bridging the digital divide can serve as a catalyst for stimulating rural entrepreneurial activity.

To uncover the mechanisms through which digital skills influence farmers' agricultural entrepreneurship, we examine the role of factor availability as a mediator, encompassing production credit, modern technology, and social capital. Our findings reveal that factor availability significantly contributes to farmers' agricultural entrepreneurship, aligning with previous research (Barnett et al., 2019; Hu et al., 2023). Moreover, we demonstrate that factor availability acts as a mediator in the relationship between digital skills and farmers' agricultural entrepreneurship. As per Yang et al. (2023), enables farmers to access essential elements of agricultural entrepreneurship, contributing to an increased success rate in farmers' entrepreneurial endeavors.

Furthermore, the study results reveal that digital skills exert a more substantial influence on farmers' agricultural entrepreneurship when coupled with improved resource conditions and development status. This confirms the view of Li et al. (2023) that the existing conditions and future development status of the household can shape the impact of digital skills on the agricultural entrepreneurship of farm households. Additionally, the impact of digital skills on the agricultural entrepreneurship of farm households surpasses its effect on non-farm entrepreneurship.

Conclusion

Main conclusions

This paper summarizes the effects and mechanisms of digital skills on farmers' agricultural entrepreneurship through theoretical analysis. This paper, based on data from the 2020−2022 Jiangsu Farmers' Household Survey, finds that digital skills can significantly contribute to farmers' agricultural entrepreneurship decisions, and each unit increase in digital skills increases the probability of farmers' agricultural entrepreneurship by 1.10 percentage points. Considering the potential endogeneity issue, the paper was estimated using instrumental variables method and PSM method, and the results confirm the causal property of the positive effect of digital skills on agricultural entrepreneurship of farm households. In addition, after multiple stability tests, the conclusion that digital skills significantly and positively act on agricultural entrepreneurship of farm households has sufficient robustness. The results of the mechanistic analysis show that digital skills can improve the probability of farmers' agricultural entrepreneurship by increasing their access to production credit, modern technology, and social capital. Heterogeneity analysis show that the positive effect of digital skills on farmers' agricultural entrepreneurship is more pronounced among households with more farming experience, greater land resources, no history of major adversity, and members who lack optimistic expectations for the future. Furthermore, digital skills also have a positive impact on farmers' non-farm entrepreneurship behavior, and the magnitude of this impact is greater than it is for AE. There are also differences between the impact of different digital skill types on different types of entrepreneurships. Digital learning and financial skills have a significant positive impact on both agricultural entrepreneurship and non-farm entrepreneurship, with digital learning skills having a greater impact on agricultural entrepreneurship and digital financial skills having a greater effect on non-farm entrepreneurship. Digital life skills do not have a significant impact on either agricultural entrepreneurship or non-farm entrepreneurship. In summary, the paper concludes that digital skills have a positive impact on farmers' agricultural entrepreneurship.

Theoretical contributions

Building on these findings, this study puts forth three theoretical contributions. Firstly, prevailing research has predominantly concentrated on the correlation between internet access and non-farm entrepreneurship, overlooking the distinctiveness of agricultural production in rural households (Romero-Castro et al., 2023; Hu et al., 2023). This study introduces a fresh perspective by exploring the comparative advantages of agricultural production in rural households and analyzing the factors that impact agricultural entrepreneurship.

Furthermore, we establish a comprehensive index of farmers' digital skills, enhancing our exploration of the relationship between digital skills and farmers' agricultural entrepreneurship. This enables a nuanced understanding that transcends the initial stage of the digital divide, shedding light on the impact of digital access, use, and skills on farmers' behavior.

Finally, this study extends beyond by incorporating a theoretical, analytical framework to analyze the mechanisms through which digital skills influence farmers' agricultural entrepreneurship, particularly focusing on factor accessibility. It delves into how digital skills augment rural households' access to resources, thereby influencing decision-making in agricultural entrepreneurship. The insights derived from this work hold significance for China and other emerging economies, offering guidance to advance internet applications and empower rural households in their entrepreneurial endeavors.

Managerial implications

The advent of the Internet era is driving the rapid development of the digital economy, bringing new development opportunities for agricultural and rural development in China and even other developing countries. Network information technology is embedded in all aspects of people's lives, changing to a large extent the way people gather information, interact socially and borrow money, thus having a broad and profound impact on farmers' entrepreneurial attitudes and behaviors. Agricultural entrepreneurship is a crucial pathway through which farmers can integrate production factors and allocate production resources effectively. It is of great significance in driving the employment and income of farmers, promoting the economic development of rural areas and narrowing the development gap between urban and rural areas (Mc Fadden & Gorman, 2016). The study suggests that the Chinese government should accelerate the construction of digital villages and the widespread application of digital technologies in rural agriculture. Therefore, this study proposes the following policy implications.

First, the government must strengthen the construction of rural ICT infrastructure, not only to improve the rural 5 G network, gigabit optical network and other hardware facilities, but also to accelerate the construction and use of big data center platforms and digital service platforms (Zhao et al., 2023). As the current level of digital skills among Chinese farmers is not yet high enough, the Government must continue to improve rural Internet coverage and the quality of digital facility services, expand access to high-quality digital resources in rural areas, and promote the open sharing of digital education and training, digital information services and other resources, so as to bridge the divide in the use of digital technology between groups, regions and urban and rural areas.

Second, governments can improve human capital to enable farmers to adapt more quickly to the wave of the digital economy, thereby facilitating the widespread use of digital technologies in agriculture. The cultivation of professional farmers in China should be used as a basis for creating a favorable environment for digital learning and training; guide farmers to proactively enhance their learning abilities; and improve their capacity to access technological, policy, and other information through the internet, thereby providing support for agricultural entrepreneurship (Arafat et al., 2020). At the same time, the work of promoting innovation and entrepreneurship with digital skills should focus on the level of digitization, intelligence, and networking of the subjects, and policy should promote the application of digital technology in farmers' production and daily life (Ehlers et al., 2021).

Third, the results of the mechanism test indicate that digital skills promote farmers' agricultural entrepreneurship through factor availability. Therefore, in the coming period, it is important to focus on building digital villages, continue to leverage the role of digital technology in the factor market; to promote the linkage between digital skills and the factor market; to enhance the accessibility of factors through digital skills, including innovative combinations of the internet and rural financial services to improve the development environment for digital payment, digital credit, and other inclusive financial services; to promote the development of digital agricultural technology extension services that provide accurate agricultural information search for farmers and promote the adoption of digital technology; and to leverage social networks on the internet for social capital using government-built social interactive platforms to enhance entrepreneurial support (Hu et al., 2023).

Finally, policy development should be targeted and differentiated in the development of the rural digital economy. In particular, the construction of digital villages and the cultivation of digital skills should avoid a "one-size-fits-all" approach, and supportive policies should be tailored toward vulnerable groups in rural areas, assisting those with farming experience to embark on entrepreneurship through the internet, thereby improving their livelihoods. Additionally, different groups' digital skill needs should be considered, rural families' access to and use of entrepreneurial information should be expanded, and opportunity losses caused by insufficient information should be alleviated.

Limitations and future research

This study has some limitations that need to be further explored in future studies. First, our study sample is limited to farmers in Jiangsu Province, which cannot fully represent the development of different regions, although there are differences in the level of development in various cities and districts in Jiangsu Province. The next step will be to keep tracking around this theme and expand the survey area to a wider range. On the other hand, this study mainly focuses on the impact of farmers' skills in utilizing the Internet to obtain various types of information on agricultural entrepreneurship decision-making, but it has not yet investigated the impact and mechanism of agricultural entrepreneurship performance, especially how the impact on the performance of sustainable agricultural development is worth exploring (Shen et al., 2022), which is the focus of future research.

Declarations of competing interest

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