



OPEN ACCESS

EDITED BY

Andy Yang,
Monash University, Australia

REVIEWED BY

Majid Ali,
Xi'an Jiaotong University, China
Xiaohuan Yan,
Northwest A&F University, China

*CORRESPONDENCE

Ruilong Zhang
✉ jgxy-zrl@lnutcm.edu.cn
Zaifang Jing
✉ jingzaifang@syau.edu.cn

RECEIVED 14 October 2025

REVISED 19 December 2025

ACCEPTED 30 December 2025

PUBLISHED 13 January 2026

CITATION

Yang X, Liu J, Zhang R, Gu L and Jing Z (2026)
Study on the pathways and mechanisms of
digital empowerment driving farmers'
participation decisions in contract farming.
Front. Sustain. Food Syst. 9:1724881.
doi: 10.3389/fsufs.2025.1724881

COPYRIGHT

© 2026 Yang, Liu, Zhang, Gu and Jing. This is
an open-access article distributed under the
terms of the [Creative Commons Attribution
License \(CC BY\)](#). The use, distribution or
reproduction in other forums is permitted,
provided the original author(s) and the
copyright owner(s) are credited and that the
original publication in this journal is cited, in
accordance with accepted academic
practice. No use, distribution or reproduction
is permitted which does not comply with
these terms.

Study on the pathways and mechanisms of digital empowerment driving farmers' participation decisions in contract farming

Xiaoli Yang¹, Jingbo Liu¹, Ruilong Zhang^{2*}, Li Gu¹ and Zaifang Jing^{1*}

¹College of Economics and Management, Shenyang Agricultural University, Shenyang, China,

²College of Economics and Management, Liaoning University of Traditional Chinese Medicine, Shenyang, China

Contract farming is regarded as an institutional vehicle for implementing sustainable agriculture at the micro-level. In the context of digital technologies reshaping agricultural value chains, exploring the pathways and mechanisms through which digital empowerment drives farmers' participation in contract farming represents a crucial research topic for advancing modern agricultural development. Based on the research data from 1,370 grape growers in Liaoning Province, China in 2023, we examined the impact of digital empowerment on farmers' decision-making in contract farming through Binary Logit model. We further employ the CMP method and Oster's omitted variable test to conduct endogeneity tests. The study found that: (i) The digital empowerment significantly improves farmers' decision-making on participating in contract farming. In terms of willingness to participate, the analytical capability plays a major promoting role, while the technological capability has an inhibitory effect. In terms of participating behavior, the positive influence of analytical capability is also robust. (ii) The digital empowerment promotes farmers' decision-making by broadening social networks and enhancing innovative awareness. The "social network—innovation awareness" exhibits a chain mediation effect between digital empowerment and farmers' decision-making. (iii) Compared with small-scale farmers, digital empowerment has a more significant impact on the contract farming participation decisions of large-scale farmers. Consequently, the research findings offer stakeholders for implementing targeted interventions aimed at boosting farmers' decision-making to participate in contract farming. The discussion section identifies the core theoretical breakthrough of this work: it traces the progression of relevant practices from local exploration to nationwide scaling and application, while highlighting their latent capacity to yield global influence.

KEYWORDS

analytical capability, connectivity capability, decision-making on participation in contract farming, innovation awareness, social network, technological capability

1 Introduction

Under the traditional agricultural production pattern in China, the degree of alignment between the modern agricultural product circulation system and the agricultural production method has decreased. Specifically, the circulation system's requirements for standardization, scale, and market-oriented operation are poorly matched with the small-scale, scattered, and

experience-based characteristics of traditional agricultural production. This places farmers in a disadvantaged position in the circulation of agricultural products, and have become major obstacles to China's agricultural supply-side structural reform and the process of agricultural modernization (Zheng and Zhang, 2021). However, this challenge is not unique to China, but reflects a global tension between smallholder production and increasingly standardized, market-oriented agricultural systems (Ma and Zhang, 2025). Contract farming is an inherent phenomenon of agricultural industrialization. It promotes organic interaction between farmers and markets. Contract farming itself constitutes a sustainable agricultural organizational form. As an institutional arrangement, it plays a crucial role in connecting farmers with modern agriculture. It is regarded as a major form of vertical collaboration in the agricultural sector, and plays a positive role in adjusting the agricultural industrial structure and expanding the agricultural industry chain (Wang et al., 2014; Lu et al., 2021). It not only reduces transaction costs, but also helps promote the transformation of agricultural product sales methods. In this study, contract farming specifically denotes written contracts, which offer notable advantages regarding legal validity, clarity, and enforceability. Written contracts delineate precise terms, particularly with respect to dispute-resolution mechanisms and performance contingencies, thereby substantially mitigating interpretive ambiguity and aligning the parties' shared understanding of the agreement. This clarity ensures all parties have a clear awareness of their rights and obligations. Written contracts carry greater legal binding force: once signed, both parties are obligated to comply, thereby mitigating performance risks. From the perspective of safeguarding parties' rights, therefore, written contracts hold distinct advantages over informal verbal agreements (Wang et al., 2014). However, in practice, farmers show low enthusiasm for engaging in contract farming. Informal market transactions remain the predominant model in agricultural production and marketing (Ding et al., 2024). Against this backdrop, there is an urgent need to identify drivers that influence farmers' decisions to participate in contract farming.

As a key measure for farmers to integrate into modern agriculture and advance the sustainable development of agriculture, farmers' participation in contracts has emerged as a prominent topic in current research. Existing studies primarily examine two dimensions of farmers' decision-making in contract farming: 1) Internal Factors: Research has analyzed the psychological perceptions, individual characteristics, and production management traits that influence farmers' participation in contract farming (Liu and Zhou, 2020; Xu et al., 2023; Li et al., 2025). Psychological perceptions include self-efficacy, risk perception, and trust. Among individual characteristics, factors such as gender, age, and educational attainment significantly influence farmers' decisions regarding contract farming. Production management traits are primarily defined by soil quality, cooperative membership, and the degree of production specialization. 2) External factors: Studies have examined the external characteristics influencing farmers' decisions from the perspectives of social norms and policy support (Vamuloh et al., 2020; Wu et al., 2021; Xu et al., 2023; Nematollahi et al., 2025). Notably, regulatory oversight, training initiatives, and advisory services have been identified as facilitators of farmers' participation in contract farming. Studies further indicate that farmers in China are disadvantaged in the development of contractual agriculture—primarily due to severe shortages of information, technology, and capital (Zheng and Zhang, 2021). A

review of existing literature indicates that although numerous factors influence farmers' decisions regarding contract farming, there is a relative scarcity of research focusing on the impact of digital empowerment on farmers' participation behaviors. Notably, existing studies conducted from a commercial perspective indicate that through digital transformation, customers gain the capacity to verify contractual components, thereby enhancing oversight of agreement terms. It enhances the transparency of the information environment and further boosts the enthusiasm for contractual participation (Zhao and Tan, 2012). These findings imply that digital technologies possess the potential to address deficiencies in contract participation. In recent years, the rapid development of internet information technology in China has not been accompanied by adequate research on the effects of digital empowerment in the agricultural domain. Therefore, it is essential to further explore how digital empowerment can enhance farmers' participation in contract farming.

Scholars have conducted extensive research on digital empowerment across multiple disciplines and fields. Within the Chinese context, studies on digital empowerment primarily focus on its implications for economic returns and social welfare (Tian et al., 2022; He et al., 2023). The research on the relationship between digital empowerment and farmers mainly focuses on the areas of green agricultural production and farmers' income growth (Zhong et al., 2023; Ma and Li, 2024). Digital empowerment is emerging as a critical new driver and opportunity for enhancing farmers' decisions regarding participation in contract farming. With the extensive penetration of the digital economy into agriculture, the construction of digital rural areas has accelerated. It has become a vital means of fostering new growth drivers for agricultural and rural development in China (Wang et al., 2023). In January 2020, the Ministry of Agriculture and Rural Affairs issued the "Digital Agriculture and Rural Development Plan (2019–2025)," which emphasizes seizing the high ground in digital agricultural development and leveraging digitalization and informatization to promote rural advancement. Significant progress in rural digitalization in China is an undeniable fact. According to the 54th Statistical Report on the Development of the Internet in China, the national internet-penetration rate had reached 78.0%, with mobile-internet adoption at 99.7% by June 2024. Concurrently, as economic development progresses and agricultural subsidy policies are implemented, numerous telecommunications companies have reduced costs and increased speeds specifically for rural areas. Thus, smartphones and computers have become indispensable "new agricultural tools" in the processes of agricultural production and consumption (Jiang and Wu, 2024). Farmers' participation in contract farming fundamentally involves the adoption of agricultural technologies (Wang et al., 2014). Digital empowerment enhances farmers' access to information, technology, and other resources. Improved availability of such resources facilitates the adoption of advanced agricultural technologies. The integration of next-generation information technologies through digital empowerment offers viable pathways for reshaping agricultural production and management practices. Against the backdrop of the national drive for digitalization and agricultural modernization, investigating how digital empowerment influences farmers' decisions to participate in contract farming will help identify pathways to advance agricultural modernization.

Across the existing literature on contract farming and digital empowerment, while valuable theoretical foundations and insightful research directions have been laid for this study, three notable gaps remain. First, current research has not paid sufficient attention to digital empowerment as a key emerging variable influencing farmers'

contract participation decisions. Moreover, current research has not thoroughly explained the intrinsic mechanisms. This disconnect has created a gap in the integration of digital technology and contract farming participation research. Second, regarding the measurement of digital empowerment, several relevant studies suffer from oversimplified indicators—relying solely on binary variables such as “internet usage status” for simplistic delineation. Such an approach fails to accurately capture the true level of farmers’ digital empowerment. Third, most existing studies analyze farmers as a homogeneous group, neglecting inherent heterogeneities among individual farmers. This homogenization assumption may undermine the practical explanatory power and applicability of research findings.

From the perspectives of digital empowerment and contract farming, this study provides a theoretical basis and practical insights to support the development of a strong agricultural nation. This paper examines three key questions: first, whether digital empowerment and its various dimensions can promote farmers to participate in contract farming. Second, through which pathway? Third, differences in the participation of farmers of different scales in Contract farming driven by digital empowerment. The study contributes by: (i) Providing micro-level evidence for the “incomplete-contract” theory in institutional economics. Extending the frontier of contract-farming research. Integrating digital empowerment with farmers’ contract decisions. This study not only identifies whether table grape growers in northern China participate in contract farming, but also provides a replicable and empirically verified Chinese model for the restructuring of agricultural value chains on a global scale. (ii) Empirically investigating the mechanisms of action through social networks and innovative awareness. Clarifying digital empowerment’s role in decision-making. (iii) Analyzing the participation of farmers of different scales in contract farming, offering insights into the conditions influencing digital empowerment and highlighting its potential in agricultural modernization.

2 Theoretical analysis and research hypothesis

2.1 Direct effects

According to Williamson (1985), the cost of capital and time associated with the acquisition and transmission of information in trading markets represent a key factor influencing the structure of production organizations (Williamson, 1985). Transaction costs primarily emerge from the combined effects of information asymmetry, bounded rationality, and opportunism. Of these factors, information asymmetry serves as the primary driver of irrational behavioral choices among farmers, thereby undermining their capacity to maximize expected utility. Based on the theory of Bounded Rationality, digital empowerment plays a crucial role in decision-making under uncertainty. It can reduce transaction costs, enabling farmers’ decisions to approximate the optimal outcomes achievable under complete rationality. For farmers, participation in contractual arrangements represents a critical decision in the context of agricultural production. Both farmers’ willingness and actual participation behavior exert a significant impact not only on their economic status but also on resource allocation and access to development opportunities. Digital empowerment thus facilitates farmers’ engagement in contractual arrangements. Building on

existing research, this study categorizes digital empowerment into three dimensions: connectivity capability, technological capability, and analytical capability (Lenka et al., 2017). Based on Delegation-based Empowerment Theory. Connectivity capability mitigates the information impact defined by Williamson. Connectivity capability serves as a prerequisite for farmers to overcome the threshold for participating in contractual arrangements, as it integrates fragmented information flows and thereby enhances participation efficiency. Technological capability refers to the ability to capture information using digital devices and apply digital technologies. It provides technical support for contract farming. Technological capability endows farmers with greater control over market timing and customer relationships, which significantly strengthens their pursuit of operational autonomy. Notably, from the perspective of transaction cost theory, contract farming can reduce the transaction risks faced by farmers. However, contract farming must rely on explicit contractual clauses to ensure the stability of cooperation. This inevitably imposes rigid constraints on farmers’ autonomy in production and operation, which essentially constitutes the “contractual costs” for farmers to participate in contract farming. Based on the resource-based view, technological capability endow farmers with broader room for maneuver in production decision-making and market strategy selection. At this point, the marginal utility of the market guarantees provided by contract farming decreases significantly for farmers with stronger technological capability. Thus, it can be seen that technological capability has a significant negative impact on farmers’ contractual participation decisions. Analytical capability involves the coordination and sharing of information. It promotes the organic integration of diverse information, knowledge, and skills. Grounded in information retrieval theory, analytical capability facilitates interaction and connection between buyers and sellers. It can reduce information friction and matching difficulties while lowering search costs (Faulkner and Laschinger, 2021). This ongoing adoption of effective information is crucial for farmers’ self-driven participation in contract farming (Aker, 2022). Therefore, we propose the following hypothesis:

H1: Digital empowerment has a significant positive effect on farmers’ contractual participation decisions, which includes willingness to participate and participation behaviors.

H1a: Connectivity capability has a significant positive effect on farmers’ contractual participation decisions, which includes willingness to participate and participation behaviors.

H1b: Technological capability has a significant negative effect on farmers’ contractual participation decisions, which includes willingness to participate and participation behaviors.

H1c: Analytical capability has a significant positive effect on farmers’ contractual participation decisions, which includes willingness to participate and participation behaviors.

2.2 Indirect effects

Drawing on the theory of embeddedness, farmers’ decisions to participate in contract farming are not driven solely by the principle of

profit maximization but are deeply embedded in specific social relations and structures (Simon, 1947). This embeddedness exhibits distinct local characteristics in the Chinese rural context: Rural China is essentially a “local society” as conceptualized by Fei (1998), with its social structure centered on the “pattern of differential associations.” Centered on the individual, this structure radiates outward in concentric circles based on “geographical ties” and “kinship bonds,” forming a social network characterized by varying degrees of intimacy that profoundly shapes farmers’ decision-making logic. Rather than formal institutions or market rules, farmers tend to rely on and trust this socially embedded network rooted in the differential mode of association when making operational decisions (Lü et al., 2021). As an intangible asset, such social networks significantly expand farmers’ access to development opportunities (Hong et al., 2021; Ma et al., 2024). Specifically, this study posits that expanding social networks can significantly increase the likelihood of farmers participating in contract farming.

Digital empowerment helps mitigate the geographical constraints inherent in farmers’ operational contexts. By facilitating the sustained maintenance of strong existing social ties and the establishment of new weak ties, digital empowerment effectively broadens farmers’ social network structures (Luo and Liu, 2022). Drawing on the theory of social network embedding, digital empowerment mitigates information redundancy within farmers’ social networks while elevating the frequency of interactions among network actors. Concurrently, this empowerment drives a significant reduction in the costs associated with social network maintenance. This ultimately achieves the simultaneous optimization of network scale (breadth) and relationship quality (Strength) (Wei et al., 2025). According to social exchange theory, in order to maximize their interests via resource exchange, individuals foster cooperative relationships driven by shared benefits that strengthen social networks (Dienesch and Liden, 1986). Therefore, we propose research hypothesis 2:

H2: Digital empowerment enhances farmers' participation in contract farming decision-making by broadening their social networks.

The innovative awareness of farmers is profoundly shaped by the confluence of China’s smallholder institutions and grape value-chain structure. Within this context, farmers’ bounded rational decision-making tends toward path dependence. Only the awakening of innovative consciousness can drive them to achieve breakthroughs. Meanwhile, viticulture is highly labor-intensive. Rapid technological evolution and knowledge renewal drive farmers beyond empirical traditions, fostering innovation. Farmers with stronger innovative consciousness are more likely to participate in contract farming. To mitigate the uncertainty associated with new agricultural technologies, farmers often adopt a wait-and-see attitude (Xue et al., 2025). Long-term contracts foster stable transaction expectations, while short-term contracts can lead to speculative behavior. Farmers with a higher innovative awareness are more likely to embrace new opportunities, as they are prepared to take risks for potentially higher returns. Prior studies suggest that contract farming represents an innovation-driven institutional arrangement (Alulu et al., 2021).

Rooted in innovation diffusion theory (Rogers, 1962), digital empowerment furnishes farmers with enhanced access to opportunities and operational convenience in agricultural production and management. Specifically, multifaceted information access

broadens perspectives and stimulates creativity, thereby enhancing innovative awareness. Moreover, the sustained impact of multi-dimensional information flows enabled by digital empowerment induces iterative updates of cognitive frameworks. When farmers observe the benefit representations associated with heterogeneous innovative behaviors, a “reference group” effect emerges under the influence of social-learning mechanisms. Consequently, it triggers a threshold-crossing in their innovative consciousness.

Therefore, we propose the following hypothesis 3:

H3: Digital empowerment enhances farmers' participation in contract farming decision-making by reinforcing their innovative awareness.

The expansion of the social network enhances innovative awareness. Chinese smallholders’ bounded rationality and relational embeddedness reconfigure the activation pathways of innovation awareness. Gao (2002) emphasizes that innovation is a gradual process embedded in specific social systems and industrial structures. The activation of innovation awareness depends on farmers’ interactions via social networks. Contract farming fundamentally involves the adoption of new technologies (Wang et al., 2014), which often entails unknown risks. Research indicates that social networks serve as informal insurance and risk-sharing mechanisms. It attenuates the utility loss associated with innovation failure (Zhang et al., 2023). Prior study emphasize that network enhances human capital and channels resources through the transmission of innovative awareness (Li and Lv, 2025). Essentially, social networks reduce information asymmetry via information bridges and lowers the psychological threshold for individuals to attempt innovation. The inherent uncertainty of innovation tends to trigger risk-averse tendencies among farmers, thereby inhibiting the initiation of behavioral decisions. Social networks address this dilemma through a dual-support mechanism: at the emotional support level, the emotional bonds forged by trust within the network alleviate farmers’ psychological anxiety and fear of loss associated with innovation failure; at the resource support level, resource complementarity and sharing among network nodes mitigate risk impacts. These dual forms of support collectively weaken farmers’ perceived innovation risk, activate their latent willingness to innovate, and facilitate the transformation of innovative awareness from the cognitive dimension to practical decision-making and behaviors. Therefore, we propose research hypothesis 4:

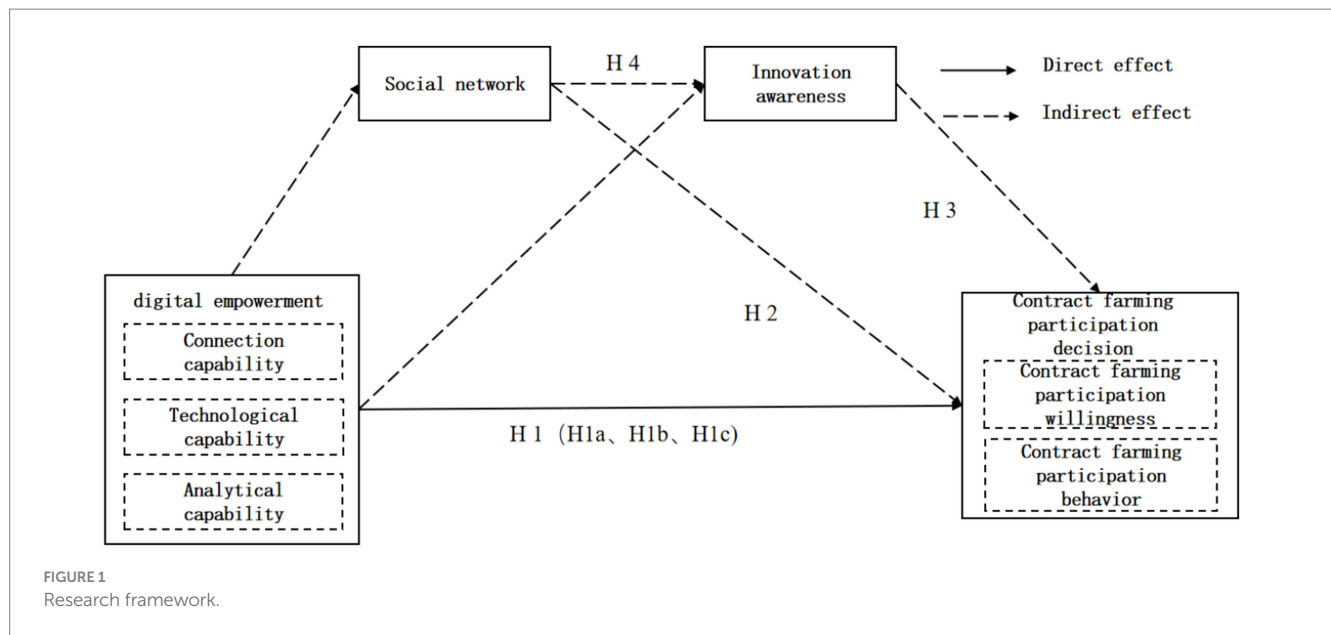
H4: Digital empowerment enhances innovative awareness by broadening social networks, thereby facilitating farmers' participation in contract farming decision-making.

Based on the preceding content and literature review, the conceptual model of the study is illustrated in Figure 1.

3 Research design

3.1 Data source

The data originate from a sample survey of grape growers conducted by the subject group in the main grape-growing areas of



Liaoning Province, China, from June to August 2023. Liaoning Province has a long history of grape cultivation and is the main grape-producing province in China. Liaoning is the second-largest province in China by both bearing acreage and aggregate grape output, and it leads the nation in the refrigerated storage capacity of table grapes. The grape industry has a pivotal position in both the regional fruit industry and the national grape industry. Grapes are characterized by perishability, high transportation costs and uneven quality. Contract farming is more likely to reduce delivery risks when trading. Therefore, it is representative to study farmers' participation decision-making on grape sales contract.

Data were collected through structured, face-to-face interviews. To ensure the typicality and representativeness of the research area and the research subjects, this study selects six core production counties in the main grape-producing areas of Liaoning Province as the research area based on the distribution characteristics of the five geographic divisions of Liaoning Province: Liaobei, Liaoxi, Liaozhong, Liaonan and Liaodong, specifically including Sujiatun District and Faku County in Shenyang, Dengta City in Liaoyang, Beizhen City in Jinzhou, Lingyuan City in Chaoyang, and Gaizhou City in Yingkou. The research sites were determined by the method of "stratified sampling + random sampling." First, sampling counties/districts were identified based on the major fresh grape-producing areas of Liaoning Province, excluding Huanren Manchu Autonomous County (a dedicated ice wine grape-producing region). Subsequently, townships were selected from each sampled county/district according to their status as key grape-producing areas, resulting in a total of 18 sampled townships. For each sampled township, 3–4 villages were randomly chosen, yielding 65 sampled villages in total. Finally, approximately 20 grape-growing households were randomly selected from each village to conduct the survey. A total of 1,412 questionnaires were collected. Considering the realities of contract farming, we further excluded samples involving respondents under 18 years old or over 80 years old, as well as those with contradictory questionnaire logic (e.g., contradictory answers to different formulations of the same core question) or abnormal values. The effective sample size is 1,370 farmers were obtained. The sample validity rate was 97.03%.

3.2 Model setting

To test hypothesis 1 and 1a, 1b, 1c, we choose Logit model. The assumptions of the Logit model are as follows: the absence of complete separation and multicollinearity, as well as the independent and identically distributed error terms following a standard logistic distribution. The Logit model deterministically maps the linear predictor onto the unit interval (0, 1) via a sigmoid transformation, thereby ensuring that all fitted values remain proper probabilities. The following models are constructed:

$$Y_i = \alpha_0 + \alpha_1 DE_i + \alpha_2 Control + \varepsilon_i \tag{1}$$

$$Y_{ij} = \beta_0 + \beta_{1j} DE_{ij} + \beta_{2j} Control + \varepsilon_{ij} \tag{2}$$

In Equation 1, Y_i denotes either the participation willingness or e-commerce participation behavior of the i th farmer which is 1 if participated and 0 otherwise. DE_i denotes the level of digital empowerment of the i th farmer. In Equation 2, Y_{ij} denotes the effect of the j th dimension of digital empowerment on either contract farming participation willingness or behavior of the i th farmer. DE_{ij} denotes the j th dimension of digital empowerment of the i th farmer. DE_{ij} ($j = 1,2,3$) represents the connectivity capability, technological capability and analytical capability of the i th farmer, respectively. *Control* denotes the control factors. α_0 and β_0 are constant term, ε_i and ε_{ij} denote the random error term.

On the basis of the above equation, the mechanism model is shown below:

$$mid_{ij} = \gamma_0 + \gamma_{1j} DE_i + \gamma_{2j} Control + \varepsilon_{1ij} \tag{3}$$

Equation 3 specifies a regression of digital empowerment on the mediating variable. mid_{ij} denotes the value of the mediating

variable taken by the i th farmer, specifically containing either social network or innovation awareness. γ_0 denotes the constant term, γ_{1j} and γ_{2j} are parameters to be estimated, ε_{ij} denotes the random error term.

3.3 Description of the variable

3.3.1 Dependent variable: farmers' contract-farming participation decision

The dependent variable consists of the willingness to participate in contract farming and participation behavior in contract farming. Both are 0–1 binary categorical variables, where 1 indicates participation and 0 otherwise. Contract farming is initially defined as a contractual arrangement between a farmer and a buyer, specifying the conditions for the production and sale of agricultural products. It encompasses both sales contracts and production contracts (Guo and Jolly, 2008). In its most basic form, a sales contract involves the parties merely agreeing on price and quantity, while the farmer independently makes production and operational decisions. However, a production contract implies that the acquirer exercises control over the farmer's production decisions, and the farmer may be required to pay for certain services provided by the acquirer (Tan et al., 2022). The contract farming discussed in this study represents a form of negotiation between buyers and farmers. Specifically, it involves signing a legally binding written sales contract under agreed-upon conditions. Under this contract, farmers supply buyers with agricultural products of a specific quantity and quality, and buyers acquire these products as agreed. Both parties comply with the agreed-upon conditions regarding the transaction price, process, and other aspects (Tan et al., 2022). Among the survey samples, 31.2% of farmers expressed willingness to participate in contract farming, while only 12.1% had actually participated. This indicates a notable gap between farmers' participation willingness and actual behavior. Willingness to participate is a necessary prerequisite for triggering actual behavior in behavioral decision-making, it provides the psychological motivation for action. However, it is a necessary but insufficient antecedent psychological variable for behavioral enactment. Translating willingness into tangible action is constrained by multiple practical barriers, leading to relatively low conversion efficiency. The observation aligned with the core tenets of "bounded rationality" (behavioral economics) and the theory of planned behavior.

3.3.2 Explanatory variable: digital empowerment

The digital empowerment process can be characterized as "getting connected" (Connection capability) → "using digital tools effectively" (Technological capability) → "disseminating and sharing information" (Analytical capability). In other words, the digital empowerment process can be conceptualized as a sequential progression: from initial digital connectivity establishment, to the proficient application of digital tools for production and management, and ultimately to the active dissemination and interactive sharing of value-added information. Thus, drawing on existing research, digital empowerment is divided into connectivity capability, technological capability and analytical capacity (Lenka et al., 2017). Connectivity capability refers to farmers' ability to access and utilize the Internet via digitized products or services. Technological capability refers to the ability to

gather information using digital devices and to effectively apply digital technologies. Analytical capacity is the ability to transfer and share digital technology and information. Refer to Table 1 for specifics.

Considering the complexity and nonlinear relationship among the indicators of digital empowerment, the synthesis of indicators is carried out by drawing on the prior research results on the multidimensional characteristics of variables (Wang and Zhang, 2025). The calculation process is as follows: In the first step, the 10 indicators related to digital empowerment are rendered dimensionless, and the entropy value method is employed to compute the weight of each indicator (Table 1). It is challenging to accurately define the importance of each dimension of digital empowerment level through subjective judgment, while the entropy weight method objectively assigns weights based on the information entropy inherent in the data, thereby effectively avoiding biases arising from subjective weighting. Furthermore, the entropy weight method can reflect the contribution of each indicator to the overall level by calculating its degree of dispersion—indicators with higher dispersion contain richer information and receive more reasonable weight assignments, in the second step, the sub-dimensional level of farmers' digital empowerment is calculated. In the third step, the sub-dimensional levels of digital empowerment are combined to derive an overall digital empowerment level (Table 2). The average digital empowerment level of sampled farmers is 0.185, which is highly consistent with the results of a representative study by Zhang et al. (2025) focusing on rural digital transformation in China. This convergence across independent research contexts not only validates the reliability of the measurement method adopted in this study but also aligns our findings with the academic consensus on the current stage of digital empowerment among Chinese farmers.

3.3.3 Mechanism variables: social network and innovation awareness

Social network is operationalized as the web of interpersonal ties formed by farmers based on kinship, friendship and other informal relations. It consists of three dimensions: social network strength, social network height and social network breadth (Chen et al., 2025; Li et al., 2025). Social network strength refers to the strength of social network relationships or the number of contacts of social network members within a defined time interval. The core of social network strength lies in "relationship closeness" and "interaction activeness." Items "S11" and "S12" are selected as measurement indicators, covering two core scenarios: "daily interaction" and "emotional maintenance," which can fully support the measurement of social network strength. Social network height indexes the occupational prestige and informal authority of the individuals with whom farmers interact (Hong and Luo, 2023). "S13" and "S14" are used to measure the height of social networks. Relatives and friends working in the government have occupations with high social recognition, which can bring indirect prestige endorsement to farmers; at the same time, such personal network resources can also enhance farmers' discourse power in social interactions. Being a major surname in the village indicates a large family population and a long history of generational settlement. In the rural acquaintance society, members of major surnames are more likely to gain the trust of neighbors and possess social influence. Social network breadth refers to the scope covered by the social network, i.e., the size of the network (Feng et al., 2024). Social network breadth is measured by items "S15" and "S16." The

TABLE 1 Digital empowerment measurement scale.

Variable name	Variable definition	Variable assignment	Mean	SD	Max	Min
C1 Connection capability	S1 Cell phone signal	1 = E 2 = 3 g 3 = 4 g 4 = 5 g	1.896	0.652	4	1
	S2 Number of cell phones and computers your family own	Unit: One	3.353	1.540	15	0
	S3 Number of hours you use your cell phone per day when you are free	Unit: Hours	2.513	1.852	10	0
	S4 Number of frequently used applications on your phone	Unit: One	5.220	5.733	55	0
C2 Technological capability	S5 Whether you use WeChat and Alipay for payments and receipts in your daily life?	Yes = 1, No = 0	0.825	0.380	1	0
	S6 Whether you would like to save good agricultural production information when you come across it	Yes = 1, No = 0	0.184	0.388	1	0
	S7 Whether you follow information on agriculture while surfing the web?	Yes = 1, No = 0	0.793	0.405	1	0
	S8 The amount you spend on online shopping per year	Unit: yuan	3,740	7,750	100,000	0
C3 Analytical capacity	S9 Whether you share agriculture-related pictures or videos on WeChat?	Yes = 1, No = 0	0.464	0.499	1	0
	S10 Number of short videos you publish online	Unit: One	36.666	107.019	1,000	0

number of relatives and friends visiting respondents' homes during the Spring Festival directly corresponds to the two core types of connection targets in farmers' social networks, and directly quantifies the coverage scope and overall scale of the social networks. Consistent with our treatment of digital empowerment, we calculate indices for the social-network construct and each sub-dimension using an identical weighting procedure. The variable definitions and corresponding values are provided in Table 3.

This paper describes innovation awareness as the attitude and tendency of individual decision makers when faced with new things, ideas and technologies. Gao (2002) proposed the theory of farmers' innovation diffusion in Agricultural Extension Science. The innovation awareness involved in this theory essentially refers to farmers' acceptance of new technologies. This study draws on Gao's research. The innovation awareness is measured by asking farmers "Would you adopt a new agricultural technology when it is publicized by the relevant government departments?" The result is an ordered multicategorical variable ranging from 1 to 4. The higher values representing a greater sense of innovation (Table 2).

3.3.4 Control variables

To isolate the causal influence of digital empowerment on farmers' contract-farming participation, we condition on the full suite of determinants repeatedly shown to sway adoption decisions (Wang et al., 2014; Liu and Zhou, 2020; Li and Wang, 2025). These span individual traits, household endowments and farm-level production characteristics. To absorb unobserved regional heterogeneity, province fixed effects are included throughout (Table 2).

4 Empirical analysis

4.1 Benchmark regression results

Prior to regression, we tested for multicollinearity among the variables. The most effective method to determine the problem of multicollinearity is the variance inflation factor (VIF), which is judged by identifying the magnitude of the inflated factor of each variable of the model. The VIF of all variables is <10, and the test for participation

TABLE 2 Explanation of indicators and statistical characteristics.

Variable category	Variable name	Variable definition and assignment	Mean	SD	Max	Min
Explained variables	Willingness to participate in contract farming	Yes = 1, No = 0	0.312	0.463	1	0
	Behavior of participating in contract farming	Yes = 1, No = 0	0.121	0.326	1	0
Explanatory variables	Digital empowerment	According to the entropy method	0.185	0.121	0.732	0.002
	C1 Connection capability		0.213	0.080	0.566	0.013
	C2 Technological capability		0.216	0.184	0.760	0
C3 Analytical capacity social network	0.169		0.185	1	0	
Mechanism variables	C4 Social network strength		0.139	0.088	0.613	0.002
	C5 Social network height		0.093	0.065	0.665	0
	C6 Social network breadth		0.162	0.136	1	0
	Innovation awareness		0.138	0.134	1	0
		When relevant government departments promote a new agricultural technology, will you adopt it? 1 = Not adopt 2 = Adopt only after seeing that others have achieved positive results 3 = Adopt only after seeing others adopt it 4 = Be brave enough to be the first to try	2.699	1.028	4	1
Instrumental variable	Annual grape-training times	Unit: Times	1.545	1.685	10	0

(Continued)

TABLE 2 (Continued)

Variable category	Variable name	Variable definition and assignment	Mean	SD	Max	Min
Control variables	Gender	1 = Male, 0 = Female	0.659	0.474	1	0
	Age	Unit: Years	53.840	9.928	79	22
	Health	1 = Unhealthy 2 = Fairly healthy 3 = Highly healthy	2.755	0.514	3	1
	Number of family laborers	Unit: Persons	2.256	0.842	9	1
	Education	1 = Elementary school and below, 2 = Middle school, 3 = High school, 4 = specialized training school, 5 = Undergraduate and above	1.866	0.676	5	1
	Planting area	Unit: Mu	8.808	7.019	85	0.5
	Planting years	Unit: Years	21.956	10.071	53	2
	Proportion of agricultural income	The proportion of agricultural income in total household income	0.880	0.185	1	0.086
	Political party member	Yes = 1, No = 0	0.135	0.343	1	0
	Village cadres	Yes = 1, No = 0	0.064	0.245	1	0
	Area dummy variables	Beizhen = 1, Others = 0	0.444	0.497	1	0
		Gaizhou = 1, Others = 0	0.347	0.476	1	0
		Lingyuan = 1, Others = 0	0.079	0.270	1	0
		Shenyang = 1, Others = 0	0.068	0.252	1	0
Dengta = 1, Others = 0		0.062	0.241	1	0	

TABLE 3 Social network and risk appetite measurement scale.

Variable name	Variable definition	Variable assignment	Mean	SD	Max	Min
C4 Social network strength	S11 The amount of money you pay for your phone bill each month	Unit: yuan	66.979	46.919	350	0
	S12 The annual amount of money spent on gift-giving	Unit: yuan	9,710	7,930	50,000	0
C5 Social network height	S13 The number of relatives and friends working in government	Unit: persons	0.752	2.055	30	0
	S14 Whether it is a major surname in the village	Yes = 1, No = 0	0.560	0.497	1	0
C6 Social network breadth	S15 The number of relatives visiting the house during the Spring Festival	Unit: persons	10.990	10.423	100	0
	S16 The number of friends who come to visit your home during the Spring Festival	Unit: persons	7.584	8.720	50	0

willingness and participation behavior shows that the maximum VIF are 1.28 and 1.35. Therefore, it can indicate that the multicollinearity among variables in this manuscript is weak and can be subjected to empirical regression analysis.

Table 4 presents average marginal effects (dy/dx) from Logit estimations of digital empowerment on farmers' contract-farming participation. Regressions (1) and (4) show the influence of digital empowerment on farmers' willingness and behavior. A backward selection method is used to remove non-significant variables until all remaining variables exceed the 10% significance test, specifications in regressions (2) and (5). Coefficient magnitudes and statistical significance are virtually unchanged, indicating that the core results are robust to variable-selection procedures.

Table 4 shows that digital empowerment exerts a significant positive effect on farmers' willingness to participate in contract farming. Specifically, higher levels of digital empowerment are associated with stronger contractual intentions. Connectivity capability does not pass the significance test, while technological capability is negatively significant at the 10% level, and analytical capability is positively significant at the 1% level. The widespread adoption of smart devices in rural areas makes connectivity less critical for participation. Contract farming is characterized by standardized production and market channel control, with its core value centered on risk mitigation and income security. In contrast, technological capability helps farmers generate higher expected returns, which relatively weakens the traditional advantage of contract farming in balancing risk and return. When spot market price fluctuations exceed the fixed price stipulated in the contract, farmers with stronger technological capability tend to adjust their pricing strategies flexibly to capture premium returns—and this behavioral choice correspondingly reduces their reliance on fixed contracts. Consequently, technological capability exerts a negative effect on farmers' willingness to engage in contract farming. Contract

participation requires information sharing and bidirectional communication, where analytical capability reduces information asymmetry, allowing farmers to identify market opportunities, lower transaction costs, and enhance their confidence in engaging in contract farming.

Columns 4–6 of Table 4 show the impact of digital empowerment on farmers' participation behavior in contract farming. The results indicate that digital empowerment exerts a positive and statistically significant effect on participation at the 10% level, and only analytical capability is significant at the 5% level. The effect of technological capability and connectivity capability are confirmed but weak. The finding indicates that farmers' capacity to disseminate information is a decisive determinant of their actual engagement in contract farming. Information and behavioral decision-making theories can account for this finding. Information and decision-making are inherently interrelated: the scientific formulation of decisions is predicated on information, and analytical capability serves as a pivotal enabler for decision-makers to screen and integrate valid information. In the context of contract farming, farmers often struggle to achieve the maximization of expected utility under conditions of complete rationality. Analytical capability, however, precisely mitigates this limitation, driving farmers' decision-making outcomes to continuously converge toward the optimal state under complete rationality and thereby creating opportunities for farmers to engage in contract farming decisions. Hypotheses H1 and H1c are validated, H1b receives partial support, and H1a is not supported.

4.2 Empirical findings on potential influencing mechanisms

① Mediation Effect Analysis. This section uses Model (3) to explore transmission mechanisms, focusing on its impact on social

TABLE 4 Estimated results of the benchmark regression model.

Variable	Willingness to participate in contract logit (dy/dx)			Behavior of participating in contract farming logit (dy/dx)		
	(1)	(2)	(3)	(4)	(5)	(6)
Digital empowerment	0.371*** (0.105)	0.375*** (0.103)		0.109* (0.058)	0.105* (0.062)	
Connection capability			0.006 (0.158)			-0.098 (0.086)
Technological capability			-0.141* (0.075)			-0.064 (0.045)
Analytical capacity			0.304*** (0.070)			0.100** (0.040)
Gender	-0.017 (0.027)		-0.008 (0.027)	-0.035*** (0.014)	-0.039*** (0.014)	-0.031** (0.013)
Age	-0.003* (0.002)	-0.003** (0.001)	-0.002 (0.002)	-0.001 (0.001)		0.000 (0.001)
Health	-0.034 (0.025)		-0.036 (0.025)	0.039** (0.018)	0.038** (0.017)	0.038** (0.018)
Education	-0.015 (0.020)		-0.018 (0.020)	-0.002 (0.012)		-0.004 (0.011)
Number of family laborers	-0.000 (0.015)		-0.001 (0.015)	-0.004 (0.009)		-0.003 (0.010)
Planting years	-0.001 (0.002)		-0.002 (0.002)	-0.001 (0.001)	0.130** (0.055)	-0.001 (0.001)
Proportion of agricultural income	-0.055 (0.070)		-0.054 (0.069)	0.133** (0.052)		0.130** (0.0547)
Planting area	0.005*** (0.002)	0.004** (0.002)	0.005*** (0.002)	0.003*** (0.001)	0.004*** (0.001)	0.003*** (0.001)
Political party member	0.032 (0.042)		0.029 (0.042)	-0.034 (0.027)		-0.035 (0.026)
Village cadres	-0.051 (0.060)		-0.051 (0.059)	-0.010 (0.039)		-0.011 (0.040)
Area dummy variables	Yes	Yes	Yes	Yes	Yes	Yes
cons	0.231 (0.654)	-0.686* (0.394)	0.178 (0.672)	-5.301*** (1.369)	-5.790*** (0.718)	-5.213*** (1.380)
N	1,370	1,370	1,370	1,370	1,370	1,370
Adj. R ²	0.028	0.025	0.035	0.145	0.142	0.150

***, **, and *, respectively, indicate significance at the 1, 5, and 10% levels. Values in parentheses () represent standard error. The same applies to the table below.

TABLE 5 Action mechanism test.

Variable	(1)	(2)	(3)	(4)	(5)
	Social network (OLS)	Social network strength (OLS)	Social network breadth (OLS)	Social network height (OLS)	Innovation awareness (Oprobit)
Digital empowerment	0.089*** (0.020)	0.037*** (0.013)	0.157*** (0.030)	0.033 (0.031)	0.409** (0.205)
Social network					1.322*** (0.381)
Control variables	Yes	Yes	Yes	Yes	Yes
_cons	0.107*** (0.026)	0.131*** (0.017)	0.103*** (0.039)	0.100** (0.041)	
N	1,370	1,370	1,370	1,370	1,370
Adj. R ²	0.080	0.209	0.071	0.018	0.023

networks and innovation awareness. Table 5 shows that digital empowerment significantly enhances the strength and breadth of social networks at the 1% significance level, while its impact on social network height is statistically insignificant. This indicates that the mediating effect of social networks is primarily exerted through their strength and breadth. By transcending geographical constraints, digital empowerment not only enables farmers to maintain strong ties rooted in kinship and geographical proximity but also serves as a bridge for cross-regional connections, facilitating the establishment of new weak ties. This serves as a pivotal bridge facilitating farmers' participation in contract farming. Notably, social stratification remains prominent among farmer groups, accompanied by persistent

resource asymmetry. These factors confine farmers within homogeneous networks and impede the formation of bridging ties that facilitate upward social mobility. Even in the era of digitalization and informatization, such phenomena have not effectively improved the height of farmers' social networks. Hypothesis H2 is supported.

Table 5 shows that the results in column (5) indicate that digital empowerment passes the significance test at the 5% level. Digital empowerment allows farmers to access broader markets and connect with various stakeholders. Digital empowerment reduces search costs and curtails innovation uncertainty. As information shifts from scarcity to abundance, subjective returns are updated via Bayesian learning. Expected returns increase, spurring innovation adoption,

TABLE 6 Bootstrap chain mediation effect.

Pathway	Coefficient	p	95% conf. interval	Bootstrap times
Dig-social network-innovation awareness-willingness	0.0049	0.000	[0.0006, 0.0112]	5,000
Dig-social network-innovation awareness-behavior	0.0063	0.000	[0.0012, 0.0138]	5,000

and this diversity stimulates new ideas and solutions, enhancing their awareness of innovation and making them more likely to engage in modernization-oriented contract farming. Hypothesis H3 is supported.

② Chain Mediation Effect Analysis. Table 5 (column 5) examines the chain mediation effect of “social networks—innovation awareness.” First, mechanism analysis reveals that innovation awareness serves as a catalytic driver of farmers’ participation in contract decision-making. Second, as shown in column (1), the coefficient for digital empowerment’s impact on social networks is significantly positive, indicating that digital empowerment enhances social networks. Additionally, column (5) demonstrates that social networks positively affect innovation awareness at the 1% significance level, suggesting the existence of a chain mediation effect between social networks and innovation awareness. Agricultural innovation is confronted with dual uncertainties stemming from natural and market risks. Individual farmers incur substantial trial-and-error costs when attempting new technologies independently, whereas the inherent trust mechanisms and mutual assistance within social networks mitigate farmers’ perceived risks and psychological resistance, providing critical “safety endorsement” for their adoption of innovations. From the perspective of social norms, key nodes in social networks often act as “innovation demonstrators”; their successful practices generate positive social incentives, while regular communication and interaction within the networks facilitate the awakening and enhancement of farmers’ innovation awareness. Hypothesis H4 is supported.

We further employ a bootstrap procedure to test the chained mediation pathways “digital empowerment → social network → innovative mindset → willingness to participate in contract farming” and “digital empowerment → social network → innovative mindset → behavior of participating in contract farming”. As shown in Table 6, the 95% confidence intervals for the indirect effects are [0.0006, 0.0112] and [0.0012, 0.0138], respectively. Neither interval spans zero, the chained mediation effects are significant.

4.3 Robustness tests

This paper conducts robustness tests in three ways. First, from the government’s perspective, it restricts samples by excluding rural elderly labor (men over 60, women over 55) as contract farming targets the working—age population (Wang et al., 2022). Second, the

paper replace the models. ① Both the Logit and Probit models are common forms of discrete—choice models. In this paper, the Probit model is used to replace the Logit model for re-regression. ② Considering the possible correlation between the random disturbance terms of the willingness and behavior of participating in contract farming, the seemingly unrelated regression model is adopted to jointly estimate the two equations. ③ Drawing on the seemingly unrelated regression framework, the Biprobit model specifies a recursive system of equations and implements the two-stage estimation via maximum likelihood. This paper therefore re-estimates the parameters using the Biprobit framework. Third, to verify the reliability of the indicator synthesis results, this study additionally adopted the equal-weight average method as an alternative approach to construct the digital empowerment level indicator. Based on the equal-weight assumption, the average method integrates all sub-indicators through arithmetic mean, eliminating reliance on data characteristics for weight assignment and featuring simplicity in operation and intuitiveness in results. As shown in Table 7, the findings of this study are not affected by the indicator synthesis method. Thus, the results of this study are robust.

4.4 Endogenous test

Farmers’ participation decision in contract farming often seek support to boost digital empowerment, causing reverse—causality endogeneity. Also, unobservable omitted variables may harm benchmark regression results, so further tests are needed for accuracy. ① reverse causation. For a binary explained variable, the CMP estimator dominates conventional 2SLS. We select the number of annual grape-training times as the instrumental variable. These training programs rely on slide decks, mobile applications and other electronic resources that closely track a grower’s digital proficiency. The frequency of training primarily reflects the intensity of knowledge and skill acquisition related to viticultural practices—mainly water and nutrient management, pest and disease control, and bunch-bagging techniques. These contents do not involve the core elements of contract farming, such as the interpretation of contractual clauses, the selection of cooperation partners, and the response to performance risks—information or skills directly relevant to “participation decisions.” The above-mentioned training is mainly conducted during the prenatal and intrapartum stages, rather than on the idiosyncratic challenges of contract farming. It meets the requirements of relevance and exogeneity. Table 8 reports positively correlated with digital empowerment at 1% level. The endogeneity test validates digital empowerment as endogenous. After CMP tests, prior results remain robust.

② There may be a problem with omitted variables. Following Oster (2019), we test the impact of potential omitted variables on the regression results. (i) Calculate β^* . If it lies within the 99.5% confidence interval of the original estimate, it indicates that the omitted variables are negligible, and the parameter estimate of the impact of digital empowerment on farmers’ willingness to participate in contracts remains reliable. (ii) Calculate the value of δ when $\beta^*=0$. If the value > 1 , it implies that, for the parameter estimate of digital empowerment’s impact on farmers’ contract participation behavior to change significantly, the explanatory power of omitted variables on it must be at least several times that of existing control variables. The

TABLE 7 Robustness test.

Variable	Restricted sample (dy/dx)		Replace model						Alternative measurement of the independent variable (dy/dx)	
			Probit (dy/dx)		SUR (dy/dx)		Biprobit (dy/dx)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Willingness	Behavior	Willingness	Behavior	Willingness	Behavior	Willingness	Behavior	Willingness	Behavior
Digital empowerment	0.442*** (0.122)	0.1424* (0.084)	0.369*** (0.105)	0.109* (0.058)	0.370*** (0.107)	0.128* (0.072)	0.376** (0.157)	0.092** (0.057)	0.493*** (0.191)	0.095* (0.067)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
cons	-0.129 (0.854)	-6.880*** (1.454)	0.095 (0.408)	-2.938*** (0.714)	0.521*** (0.139)	-0.116 (0.093)			-0.718 (0.645)	-2.922** (1.435)
p-value for no contemporaneous correlation test					0.000					
Wald							263.24***			
N	946	946	1,370	1,370	1,370	1,370	1,370	1,370	1,370	1,370
Adj. R ²	0.025	0.171	0.035	0.143	0.040	0.114			0.040	0.025

TABLE 8 Regression results of instrumental variables.

Variable	CMP		
	First stage	Second stage	
	Digital empowerment	Willingness	Behavior
Digital empowerment		0.017*** (0.007)	0.024*** (0.005)
Number of training sessions	0.008*** (0.002)		
Atanhrho-12	0.089*** (0.027)		
Control variables	Yes	Yes	Yes
LR		191.96***	308.82***
N	1,370	1,370	1,370

results show that the digital empowerment’s calculation results are within the 99.5% confidence interval and the value is 2.054, which is greater than 1. Hence, the coefficient on farmers’ contract participation behaviors is stable and omitted variables do not threaten our core conclusions.

4.5 Heterogeneity analyses

Developing large-scale agricultural operation is both the scholarly consensus and a cornerstone of China’s agricultural policy (Hu et al., 2024; Su and Luo, 2024). Yet, in an increasingly digital economy, a pivotal question remains: do larger farms leverage digital tools to integrate more seamlessly with expansive markets? Put differently, does digital empowerment disproportionately facilitate contract-farming participation among large-scale producers? To answer these questions, we explore the impact of digital empowerment on the

contract-farming participation decision of different farmer groups, which can more clearly interpret the boundary conditions for the effectiveness of digital empowerment.

Lacking a rigorous theoretical threshold, we follow convention and partition growers by cultivated area. Guided by prior work and constrained by subgroup sample sizes, we classify farms exceeding the sample mean of 8.808 mu as large-scale; all others are deemed small-scale. In reality, households typically run family enterprises. In practice, a couple jointly manages three grape greenhouses, covering an area of about 9 Mu. Dividing by the average is close to the actual situation, indicating that the classification method is reasonable.

Digital empowerment has a heterogeneous impact on farmers’ contract-participation decisions (Table 9). For participation willingness, it passes a 5% level significance test for all farmers, with a slightly larger coefficient for large-scale ones. For behavior, it significantly affects large-scale farmers at the 10% level but not small-scale ones. It boosts willingness for all, yet only impacts large-scale farmers’ actions. The results indicate that digital empowerment facilitates contract farming participation among farms that exceed a critical scale. We conduct a sensitivity analysis on the classification threshold of farm size, with the analysis anchored in the sample mean. Following the existing literature (Yusup and Li, 2025), we use the median of the planting area (7 mu) as an alternative grouping criterion. Based on this criterion, we re-estimate the regression model. The results indicate that the core empirical findings remain substantively unchanged, thereby providing compelling evidence for the robustness of the findings presented in this study.

5 Conclusion and suggestion

From the perspective of digital empowerment, this paper explores the impact paths and mechanisms of digital empowerment and its various dimensions on farmers’ contract participation decision based on the micro-survey data of grape growers in the areas of Liaoning Province, China. The aim is to provide ideas and perspectives for

TABLE 9 Heterogeneity analysis.

Variable	Willingness (dy/dx)		Behavior (dy/dx)		Willingness (dy/dx)		Behavior (dy/dx)	
	Larger-scale farmers	Small-scale farmers	Larger-scale farmers	Small-scale farmers	Larger-scale farmers	Small-scale farmers	Larger-scale farmers	Small-scale farmers
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Digital empowerment	0.359** (0.160)	0.354** (0.138)	0.156* (0.088)	0.027 (0.095)	0.420** (0.219)	0.397** (0.215)	0.380* (0.222)	0.153 (0.108)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
_cons	-0.322 (1.069)	0.284 (0.071)	-5.072*** (1.444)	-5.198*** (1.426)	-0.524 (2.693)	0.761 (2.616)	-0.345*** (1.622)	-0.614*** (4.038)
Test for differences in coefficients among groups	0.216		-1.112**		0.205		-1.108**	
N	561	809	561	809	698	672	698	672
Adj. R ²	0.038	0.046	0.034	0.118	0.156	0.126	0.104	0.126

helping farmers integrate into the development of modern agriculture through digital means. The following conclusions are drawn:

(i) digital empowerment positively impacts farmers’ willingness and behavior in contract participation. Analytical capability promotes participation willingness, while technological capability restrains it. The promoting effect of analytical capability on participation behavior is also evident. (ii) Digital empowerment promotes farmers’ decision-making on contract participation by broadening their social networks and enhancing their innovation awareness. The “social network-innovation awareness” plays a significant chain-mediating role. (iii) Compared with small-scale farmers, digital empowerment has a greater impact on large-scale farmers’ decisions. Compared with prior studies, this paper not only enriches the research on the antecedents and action mechanisms of farmers’ decision-making in contract farming, but also conducts a group-by-group discussion of the research results, revealing the development potential of digital empowerment in the process of agricultural modernization. It provides new ideas for the formulation and implementation of agricultural policies, and puts forward the following countermeasures and suggestions:

(i) We propose a new paradigm of “digital empowerment-driven contract farming,” which is a novel agricultural governance model centered on digital core driving, forces to reshape agricultural value chain relationships. We recommend implementing a “Digital Lead-Goose” initiative that cultivates technologically adept, influential farmers as digital intermediaries. This program should transcend conventional skills training and instead prioritize enhancing the accessibility and functional utilization of information-sharing platforms. (ii) We propose the “dual-wheel drive” of platform construction and incentive mechanism aims to realize the transformation of collective action logic from “mobilized participation” to “endogenous synergy.” Actively build public exchange and mutual assistance platforms led and participated by multiple subjects such as village cadres and management talents. Establish a digital platform for risk sharing, rely on digital technology to achieve precise risk assessment and multi-party risk sharing. Strengthen the publicity and incentive mechanism for innovation demonstrators. (iii) We propose a “value

chain power reconfiguration” model, aiming to rebalance the power distribution pattern in the agricultural value chain through digital empowerment means. On the one hand, with large-scale farmers’ participation in contract farming as the core. Optimize the signing mechanism of contract options, fully consider farmers’ interest demands. Give full play to their demonstration and leading role. On the other hand, in response to the practical dilemma of limited sales channels for small farmers. It is recommended to establish a differentiated regionally adapted marketing support system. Establish a new value distribution mechanism, so that small farmers can also share the value-added benefits brought by the digital economy.

6 Discussions

Compared with previous studies, this paper not only enriches the antecedent research on farmers’ participation decisions in contract farming, but also conducts group-wise analyses of the findings to reveal the developmental potential of digital empowerment in the process of agricultural modernization. It further investigates the mediation effect of social networks and innovation awareness, and identifies a serial mediation effect wherein the independent variable exerts its influence on the dependent variable through multiple mediating variables in a sequential manner. It addresses the extant gap regarding the unclear mechanism through which digital empowerment affects farmers’ contract participation decisions. Prior studies proxy digital empowerment with simple indicators, such as mobile-phone or internet use. In this paper, the digital empowerment process can be characterized as “getting connected” (Connection capability) → “using digital tools effectively” (Technological capability) → “disseminating and sharing information” (Analytical capability). Empirical results indicate that digital empowerment significantly promotes farmers’ decisions to participate in contract farming, a conclusion consistent with enterprise-level findings on digital empowerment and contract participation (Zhao and Tan, 2012). This extends the literature on factors influencing farmers’ contract-participation decisions and deepens our understanding of

the underlying decision-making process. Social networks and innovation consciousness constitute key mechanisms via which digital empowerment influences farmers' contract participation, with the "social network → innovation consciousness" pathway functioning as a chained mediator. These findings broaden the application scope of social networks and innovation consciousness and uncover the internal mechanism by which digital empowerment affects farmers' engagement in contract farming. Moreover, the impact of digital empowerment on contract participation varies significantly between large-scale and households. It offers new insights for the formulation and implementation of agricultural policies. Although this study is grounded in the regional practical context of grape cultivation in Liaoning Province, its theoretical and empirical contributions have transcended the limitations of a specific geographical scope.

First, as a representative of large-scale cash crops in China, Liaoning's industrial characteristics exhibit substantial similarity with major cash-crop-producing regions nationwide (e.g., Shandong, Henan, Hebei). This "most-similar" design ensures the findings transcend geographical boundaries. Second, the core variables constructed in this study have formed distinctive constructs rooted in the Chinese local context. The key findings, validated through rigorous robustness tests, offer theoretical reference and empirical insights for related research across different regions and economic crop types. Third, grounded in the unified institutional framework of the National Digital Rural Strategy, the decision-making framework for contract farming participation and the policy intervention pathways constructed in this paper essentially represent the institutionalized implementation of national strategies at the local level. It provides replicable policy instruments for major fruit and vegetable producing regions nationwide. The study's contributions not only augment micro-level empirical evidence on farmers contractual participation decisions in China, but also enrich meso-level theories on digital economy empowerment in agriculture. Notably, the adaptability dilemma between smallholder production models and market-oriented circulation systems addressed herein is not unique to China, but rather constitutes a universal challenge in global agricultural value chain reconfiguration. Consequently, the distilled digital transformation pathways and policy logic serve both as a theoretical mapping of China's agricultural modernization and as a referential framework for similar agricultural economies. This represents a theoretical breakthrough advancing from local exploration to nationwide scaling and eventually to global relevance.

7 Limitations

Although in this study, we conducted theoretical and empirical analyses in a systematic way, there are still some limitations to be addressed. Firstly, in this study, we found that farmers with participation willingness have not fully translated this into actual behavior, as the transformation process is constrained by multiple practical barriers. It should be noted that this research focuses primarily on the impact and mechanism of digital empowerment on farmers' contractual participation decisions. Consequently, the influencing factors of this willingness-behavior gap were not included as core variables for empirical testing, but we argue that this presents a highly promising direction for future in-depth exploration.

Subsequent research could further investigate the underlying drivers of this gap and develop targeted intervention strategies. Secondly, some constructs were measured using single items. Although the definition of these constructs in this study strictly adheres to well-established literature, single-item measurements may somewhat compromise the validity of construct assessment. Building on this, future research could develop comprehensive multi-dimensional, multi-item scales through systematic literature reviews and in-depth expert interviews. This approach would enable more comprehensive and precise capture of the constructs' essence, further enhancing the scientific rigor and validity of measurement in related research. Thirdly, constrained by time and resources, the present study is restricted to cross-sectional data. Future research should therefore prioritize the construction of multi-period, multi-regional panel surveys or quasi-experimental designs to explore the long-term effects. To furnish policymakers with comprehensive, high-resolution evidence for effective policy design and implementation.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Shenyang Agriculture University. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

XY: Validation, Data curation, Supervision, Conceptualization, Funding acquisition, Writing – review & editing, Investigation, Writing – original draft. JL: Software, Writing – review & editing, Formal analysis, Methodology, Resources, Validation, Writing – original draft. RZ: Supervision, Conceptualization, Writing – review & editing, Investigation, Writing – original draft, Formal analysis. LG: Writing – original draft, Writing – review & editing, Investigation. ZJ: Writing – review & editing, Investigation, Project administration, Writing – original draft, Funding acquisition.

Funding

The author(s) declared that financial support was received for this work and/or its publication. This research paper is derived from the National Natural Science Foundation Project, with the project number: 72373101, and the Liaoning Provincial Education Department Project, with the project number: JYTMS20231329.

Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declared that Generative AI was not used in the creation of this manuscript.

Any alternative text (alt text) provided alongside figures in this article has been generated by Frontiers with the support of artificial

intelligence and reasonable efforts have been made to ensure accuracy, including review by the authors wherever possible. If you identify any issues, please contact us.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

- Aker, J. (2022). Dial "a" for agriculture: a review of information and communication technologies for agricultural extension in developing countries. *Agric. Econ.* 48, 631–647. doi: 10.1111/j.1574-0862.2011.00545.x
- Alulu, J., Jakinda Otieno, D., and Oluoch Kosura, W. (2021). Comparison of technical efficiency and technology gaps between contracted and non-contracted vegetable farmers in Western Kenya. *Cogent Food Agric.* 7, 30–54. doi: 10.1080/23311932.2021.1910156
- Chen, Z., Li, X. J., and Xia, X. L. (2025). A study on the impact of participation in contract farming on farmers' quality and safety production behaviors: based on the perspective of spatial spillover effects. *Agric. Technol. Econ.* 3, 87–105. doi: 10.13246/j.cnki.jae.2025.03.001
- Dienesch, R. M., and Liden, R. C. (1986). Leader-member exchange model of leadership: a critique and further development. *Acad. Manag. Rev.* 11, 618–634. doi: 10.2307/258314
- Ding, H., Zhang, R., and Tan, Y. (2024). Innovative agricultural product production and marketing system: promoting organic linkage between smallholders and modern agricultural development. *Issues Agric. Econ.* 2, 121–134. doi: 10.13246/j.cnki.jae.20230908.003
- Faulkner, J., and Laschinger, H. (2021). The effects of structural and psychological empowerment on perceived respect in acute care nurses. *J. Nurs. Manag.* 16, 214–221. doi: 10.1111/j.1365-2834.2007.00781.x
- Fei, X. T. (1998). From the soil: the foundations of Chinese society. Beijing: Peking University Press.
- Feng, X., Shi, X., and Zhao, Z. (2024). The impact of geographical indication agricultural products on farmers' livelihood vulnerability and well-being: a case study of the arid highland area in the Yellow River Basin. *Geogr. Res.* 43, 2702–2720. doi: 10.11821/dlyj020230972
- Gao, Q. J. (2002). Agricultural extension studies. Beijing: China Agricultural Press.
- Guo, H., and Jolly, R. W. (2008). Contractual arrangements and enforcement in transition agriculture: theory and evidence from China. *Food Policy* 33, 570–575. doi: 10.1016/j.foodpol.2008.04.003
- He, S., Yang, S., Razzaq, A., Erfanian, S., and Abbas, A. (2023). Mechanism and impact of digital economy on urban economic resilience under the carbon emission scenarios: evidence from China's urban development. *Int. J. Environ. Res. Public Health* 20, 44–54. doi: 10.3390/ijerph20054454
- Hong, W. J., and Luo, B. L. (2023). The institutions cultivated: rice cultivation, collective action, and land rights stability. *Southern Econ.* 7, 1–20. doi: 10.19592/j.cnki.scje.402219
- Hong, M. Y., Yang, X. J., and Xu, Y. C. (2021). Clan networks and the resource allocation effects of land transfer: a blessing or a curse? *Econ. Rev.* 3, 145–164. doi: 10.19361/j.er.2021.03.09
- Hu, X. Y., Xu, J. H., and Luo, B. L. (2024). The new round of land rights confirmation promotes scaled operation: evidence from discrete and consolidated land transfers. *Econ. (Q.)* 24, 1533–1549. doi: 10.13821/j.cnki.ceq.2024.05.10
- Jiang, W. G., and Wu, K. (2024). The practical logic of rural collective economy promoting farmers' common prosperity: based on the experience of "common Prosperity Village" construction in Hejiayan Village, Chongqing. *Rural Econ.* 10, 12–23. doi: 10.26957/j.cnki.cn51-1029/f.2024.10.002
- Lenka, S., Parida, V., and Wincent, J. (2017). Digitalization capabilities as enablers of value co-creation in servitizing firms. *Psychol. Mark.* 34, 92–100. doi: 10.1002/mar.20975
- Li, J. Y., Luo, L., and Fu, X. H. (2024). The impact of multidimensional support on the green production transformation in agriculture: evidence from 562 rice growers in Sichuan Province. *Resour. Environ. Arid Areas* 38, 69–79. doi: 10.13448/j.cnki.jalre.2024.245
- Li, W., and Lv, B. (2025). The impact of industry–university–research collaboration on the development of new quality productive forces: mediating effect of digital innovation level and moderating role of executives' innovation awareness. *J. Suzhou Univ. Sci. Technol. (Soc. Sci. Ed.)* 42, 28–37. Available online at: <http://dianda.cqvip.com/Qikan/Article/Detail?id=7201083751>
- Li, J., Sun, J., and Wang, M. (2025). Income effects of the "leading enterprises + farmers" in pig farming: a perspective based on transaction characteristics. *China Agric. Resour. Zoning*, 46, 194–207.
- Liu, X., and Zhou, L. (2020). Contractual attribute arrangements in contract farming: farmers' risk attitudes and contract choice decisions. *J. Nanjing Agric. Univ. (Soc. Sci. Ed.)* 20, 140–148. doi: 10.19714/j.cnki.1671-7465.2020.0030
- Lü, J., Liu, H., and Xue, Y. (2021). Risk aversion, social networks, and farmers' excessive use of fertilizers: evidence from corn growers in Northeast China. *Agric. Technol. Econ.* 1, 4–17. doi: 10.13246/j.cnki.jae.2021.07.001
- Lu, Y., Xiang, P., and Yu, L. (2021). Does contract farming promote farmers' adoption of organic agriculture? Evidence from a quasi-natural experiment in Xiangxi, Hunan, China. *Chin. J. Eco-Agric.* 31, 1683–1694. doi: 10.12357/cjea.20230080
- Luo, M. Z., and Liu, Z. Y. (2022). Adoption of digital technology, expansion of social networks, and farmers' common prosperity. *Southern Econ.* 3, 1–16. doi: 10.19592/j.cnki.scje.391614
- Ma, X. L., Guo, Y. F., and Jin, B. H. (2024). From "cooperative + company" to cooperatives running companies: how organizational model transformation promotes the value realization of agricultural ecological products. *China Rural Econ.* 10, 42–63. doi: 10.20077/j.cnki.11-1262/f.2024.10.003
- Ma, R., and Li, L. (2024). The impact of digital literacy on tea farmers' adoption of multi-stage organic fertilizer. *Chin. Agric. Resour. Reg. Plan.* 45, 22–36.
- Ma, R. H., and Zhang, C. (2025). Rural land transfer and international competitiveness of Chinese agricultural products: based on export technology complexity. *Chin. J. Agric. Resour. Reg. Plan.*, 1–25. Available online at: <https://link.cnki.net/urlid/11.3513.S.20251124.1910.012>
- Nematollahi, M., Guitoumi, A., Heydari, J., and Gerbrandt, E. M. (2025). Win-win contract farming in dual-channel agribusiness supply chains under yield, quality, and price uncertainty. *Int. J. Prod. Econ.* 286:109635. doi: 10.1016/j.ijpe.2025.109635
- Oster, E. (2019). Unobservable select and coefficient stability: theory and evidence. *J. Bus. Econ. Stat.* 2, 187–204. doi: 10.1080/07350015.2016.1227711
- Rogers, E. M. (1962). Diffusion of innovations. New York: Free Press.
- Simon, H. A. (1947). Administrative behavior: a study of decision processes in business organization. New York: Macmillan Press.
- Su, K. Y., and Luo, B. L. (2024). Can unified planting promote farmers' green production behavior? — a case study on the reduced use of chemical fertilizers and pesticides. *J. Huazhong Agric. Univ. (Soc. Sci. Ed.)* 5, 44–56. doi: 10.13300/j.cnki.hnwkxb.2024.05.005
- Tan, Y. F., Lu, Q., and Zhang, S. X. (2022). Can contract farming promote green production transformation of farmers? *Agric. Technol. Econ.* 7, 16–33. doi: 10.13246/j.cnki.jae.20220428.001
- Tian, H., Wang, A., and Zhu, Z. (2022). Digital empowerment: the impact of internet use on farmer credit and its heterogeneity—evidence from choice experiments. *Agric. Technol. Econ.* 4, 82–102. doi: 10.13246/j.cnki.jae.2022.04.008
- Vamuloh, V. V., Kozak, R. A., and Panwar, R. (2020). Voices unheard: barriers to and opportunities for small farmers' participation in oil palm contract farming. *J. Clean. Prod.*, 275–288. doi: 10.1016/j.jclepro.2020.121955

- Wang, J. H., Dou, L. L., and Wang, Y. (2022). The impact of agricultural marketization on the resource utilization behavior of livestock and poultry waste under environmental regulation policies. *China Rural Econ.* 1, 93–111. Available online at: https://kns.cnki.net/kcms2/article/abstract?v=7KCVMXbQLqJUEm6xYMq4iB8KxAGwv-h806klSaOQUN2Ctt9h9aLRV4yA9Mi9WiuG-E9cW8ftYlNkmEenOyNmgQ4mIDJniP0zlr5VWwiiQzinaKZyhhK5hJ8VFyZT3Gz7Tt4xtO9b1DWdXw1xZi1pfKq898aV8n_aIL-HQOVb8=&uniplatform=NZKPT
- Wang, D. X., Peng, Z. Q., and Li, L. (2023). Measuring and evaluating the integration development level of China's digital economy and agriculture. *China Rural Econ.* 6, 48–71. doi: 10.20077/j.cnki.11-1262/f.2023.06.004
- Wang, H. H., Wang, Y., and Delgado, M. S. (2014). The transition to modern agriculture: contract farming in developing countries. *Am. J. Agric. Econ.* 96, 1257–1271. doi: 10.1093/ajae/aau036
- Wang, Z., and Zhang, X. (2025). Study on the spatial network structure characteristics of tourism resource development in the Wuling Mountain area and its social welfare effects. *J. Nat. Resour.* 40, 912–933. doi: 10.31497/zrzyxb.20250404
- Wei, P., Cai, R., and Yan, J. (2025). Research on the network characteristics and driving mechanisms of digital economy policy diffusion: a social network analysis based on 533 policy texts. *J. Manag.* 38, 97–113. doi: 10.19808/j.cnki.41-1408/F.2025.0007
- Williamson, O. E. (1985). *The economic institutions of capitalism: firms, markets, relational contracting*. New York: Free Press.
- Wu, M., Wang, L. L., and Zhao, B. H. (2021). Heterogeneity of farmers' endowments and agricultural contract choices. *Stat. Decis.* 37, 172–176. doi: 10.13546/j.cnki.tjyjc.2021.02.037
- Xu, G., Tan, Y. F., and Lu, Q. (2023). Exploring the pathways for recovery of production post-pandemic: a study from the perspective of contract farming. *Agric. Econ. Manag.* 4, 112–126. doi: 10.3969/j.issn.1674-9189.2023.04.010
- Xue, Y., Yang, C., and Zhang, Y. (2025). From "one flower blooms alone" to "a hundred flowers blossom": how rural entrepreneurship diffusion drives agricultural industrial cluster development. *China Rural Econ.* 3, 41–60. doi: 10.20077/j.cnki.11-1262/f.2025.03.004
- Yusup, G., and Li, X. Q. (2025). Heterogeneous impacts of the digital economy on low-carbon transition of Chinese cities: from the perspective of urban sprawl and factor distortion. *Sci. Technol. Manag. Res.* 45, 199–210. Available online at: <http://m.qikan.cqvip.com/Article/ArticleDetail?id=7201257364>
- Zhang, B., Guo, F., and Sun, L. (2023). Formal institutions, informal institutions, and internal income disparities in rural areas: a perspective based on digital inclusive finance and social networks. *Southern Finance* 4, 19–32. doi: 10.3969/j.issn.1007-9041.2023.04.002
- Zhang, J. H., Yang, K. F., and Zhao, W. C. (2025). Empowerment through fingertips, shared prosperity across fields: how does digital technology narrow the income gap among farmers? *J. Financ. Econ.* 51, 34–48. doi: 10.16538/j.cnki.jfe.20250617.402
- Zhao, Y., and Tan, Z. B. (2012). E-commerce, bank credit, and financing of small and medium enterprises: a theoretical model based on information economics. *Econ. Res.* 47, 99–112. Available online at: https://kns.cnki.net/kcms2/article/abstract?v=7KCVMXbQLqJ52xe_QqxsdNYwCZjp6NWHALTR0IW9Gj6joqYxW3-OLJPUwW8OTxr7Q_FV0NvGJR0ONoaySO2QHb2njrNdweKcyKAdzZK-8rwjZhQ55w1xQ_EBWylgsrJgzvTeagkXl2Fb5IRka8wltHvHz9MYggi&uniplatform=NZKPT
- Zheng, L., and Zhang, X. (2021). Social capital, information availability, and farmers' participation in contract farming: evidence from a survey of 534 farmers in Inner Mongolia. *J. Arid Land Resour. Environ.* 35, 28–33. doi: 10.13448/j.cnki.jalre.2021.035
- Zhong, W., Li, D., and Luo, B. (2023). Digital empowerment: promoting small farmers' integration into modern agricultural development—evidence from national micro-data. *J. Jinan Univ. (Philos. Soc. Sci. Ed.)* 45, 81–93. doi: 10.13546/j.cnki.tjyjc.2021.02.037