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Can digital technology use enhance livelihood capital for mining farmers? A moderated mediation model

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In the context of digital rural construction, based on the theory of livelihood capital, this paper uses 312 survey data collected in mining areas of Shanxi Province in 2023 as a sample, and uses hierarchical regression and bootstrap methods to empirically test the impact path of digital technology use on farmers' livelihood capital. Among them, the hierarchical regression method tests the main effect and mediation effect, and the bootstrap method tests the robustness of the mediation effect and the moderated mediation effect. The results show that the use of digital technology significantly improves the level of farmers' livelihood capital. Collective action plays a mediating role in the relationship of this impact path. Risk perception positively regulates the relationship between digital technology use and collective action, indirectly affecting livelihood capital through collective action. Heterogeneity analysis shows that the improvement effect is more significant among male and elderly farmers. Further analysis shows that the frequency of online shopping, leisure and entertainment, and business activities all positively impact livelihood capital, among which online business activities have the most significant impact. The increase in household mobile phone service fees and the popularization of online shopping help stimulate the potential for capital appreciation, but the marginal effect is decreasing. Based on this, policy recommendations are put forward, such as strengthening digital technology training for farmers and supporting the combination of production and operation.

KEYWORDS

livelihood capital, digital technology use, collective action, risk perception, mining farmers, less developed regions

1 Introduction

As a central coal resource province, Shanxi Province, with about 25% of China's resource reserves identified and retained in coal resources, mining development is an essential pillar of local economic construction and social development. Of the 118 counties in the province, up to 94 counties and districts are rich in coal resources, 91 of which have coal mines for mining operations. Long-term high-intensity coal mining activities, while promoting rapid economic growth, have profoundly altered the natural ecological patterns around the mining areas, exacerbating environmental vulnerability (Zhou et al., 2022) and directly threatening the livelihood security of farmers engaged in monoculture farming for subsistence development. Farmers in mining areas face the transformation and restructuring of their livelihoods, and the trend of part-farming and off-farming is becoming increasingly evident (Feng et al., 2024), and those who cannot escape from the countryside fall into a new poverty trap.

The theory of sustainable livelihoods, first proposed by Chambers and Conway (1992), emphasizes the ability of individuals or households to achieve their livelihood goals through

diversified activities and asset portfolios without compromising the natural resource base. This theory argues that a rural household's livelihood depends not only on its income level but also on its livelihood capital, which includes human capital, natural capital, physical capital, financial capital, and social capital (Scoones, 1998). These livelihood capitals are interdependent and mutually transformative, forming the foundation for households to cope with external risks, improve their well-being, and achieve sustainable development (Ellis, 2000). Therefore, livelihood capital has become an important analytical framework for measuring rural household well-being and sustainable development potential, and has been widely used in research fields such as poverty governance, environmental management, and rural revitalization (Tao and Wall, 2009).

Within this theoretical framework, the advancement of digital transformation provides a new path for enhancing farmers' livelihood capital. The implementation of digital rural development, through the introduction of technologies such as the internet, mobile communications, and digital platforms, has significantly improved farmers' ability to access information, allocate resources, and participate in the market. Taking internet technology, a widely used digital technology, as an example, statistics released by the China Internet Network Information Center (CNNIC) show that by December 2023, the number of rural internet users in my country had reached 326 million, and the internet penetration rate in rural areas was 66.5%, an increase of 4.6 percentage points from 2022. This trend indicates that digital technology is becoming a key driving force for promoting sustainable livelihood transformation in rural areas. Research has found that the application of digital technology can effectively alleviate information asymmetry among farmers in agricultural production and marketing, optimize resource allocation (Harou et al., 2022), reduce household poverty vulnerability (Zhao et al., 2025), and encourage farmers to adopt non-agricultural livelihood strategies (Liu and Su, 2022), thereby increasing household income (Liu and Liao, 2024). However, the diffusion of digital technology is uneven. Schradie (2018) points out that due to the existence of a "digital divide," significant differences exist between different social groups in their ability to access and apply technology. Farmers and small-scale miners, as vulnerable labor groups in many parts of the developing world (Del Prado-Lu, 2017), have varying degrees of digital literacy, and their ability to utilize digital technologies and benefit from digital achievements is weaker than that of other groups (Ding, 2025). To a certain extent, they are marginalized and face difficulties in participation, further widening the gap between them and more advantaged groups (Yi et al., 2025). Therefore, the specific manifestations of the uplifting effects of digital technology among farmers in mining areas require further investigation.

For mining households, the growth of livelihood capital depends on the environmental changes in resources and various social resources formed by ties of geography, kinship, and blood, which rely on multiple collaborations of micro-farmers voluntarily (Ostrom, 2000). Collective action is an effective mechanism to address the plight of "smallholders" in developing countries in relation to "big markets" and to enhance the market performance of smallholders (Ochieng et al., 2018). For example, collective action has helped farmers in Central America to reduce the cost of entry into the relevant market (Hellin et al., 2009); smallholder farmers in the Philippines have significantly improved their economic returns and productivity by sharing risks and reducing costs through collective

action (Oakeshott, 2016); and villagers in the village of Xiawu, Tibet, have participated in collective action spontaneously, forming a system of "digging three, repairing two, and taking turns to work," which has brought tremendous vitality to the livelihoods of farmers (Sun et al., 2024). According to the 2021 Analysis Report on the Development of New Agricultural Management Subjects in China, the number of farmers' cooperatives in China at the end of 2020 was 5.9 times that of a decade ago, with the overall number stabilizing at more than 2.2 million. However, in terms of growth rate, the growth rate of the number of farmers' cooperatives has narrowed to 1.4%, and there are still a certain number of "empty shell" cooperatives, so the development of rural collective action is not optimistic (Hu et al., 2017). The reasons for this are found to be: under the background of "big country, small farmers," namely, a large population, high pressure from agricultural market demand, small scale of operation of farmers, strong agricultural self-sufficiency, low commodity rate, the lack of per capita resource endowment, severe fragmentation of arable land and the continuous fragmentation of farm households have led to the decline of collective action in rural China (Wang and Zang, 2020); and the existence of cognitive bias, stakeholder demand challenges and the crisis of trust among participants in the marketization of rural land in China have all contributed to the enormous difficulties of collective action (Zhou et al., 2024). Mining farmers have also significantly reduced their collective action capacity due to resource depletion and labor outflow (Wang et al., 2016).

The emergence of digital technologies has provided necessary information support and technological underpinnings for mining farmers to carry out collective action, not only allowing organizers to operate purposefully (Cardoso et al., 2019) but also influencing the lifestyles of the participants (Young et al., 2019), with more and more farmers being willing to engage in information sharing, technological learning, risk-sharing, and resource integration (Birner et al., 2021). Agriculture is inherently risky, dependent on natural ecosystems, including temperature, rainfall, pollution, crop diseases, and price variations due to market imperfections (Singla and Sagar, 2012). As farmers' experience of disaster increases, their risk perception is stronger (Li and Lin, 2023). The study found that farmers' perception of health risks is the strongest and that most farmers in China have shifted their thinking from "having enough to eat" to "pursuing a better and healthier life" (Zhou et al., 2022). The perception of climate and market risks also significantly impacts farmers' adaptive behavior (Yarong and Minpeng, 2021). In the face of risk, people try to avoid it by strengthening interpersonal relationships and seeking knowledge of best practices available to others in similar situations. So, does the level of risk perception impact the relationship between digital technology and collective action?

Existing studies provide valuable references for enhancing farmers' livelihood capital. However, there is still room for expansion as follows: (1) Past studies have examined the effects of digital technology use and collective action on farmers' livelihoods, and seldom have included all three in the same theoretical analytical framework, comprehensively exploring the logical role of farmers' collective action in the relationship between the paths of digital technology use in influencing the livelihoods of farmers, as well as the role that the perception of risk plays in it. (2) There is a lack of targeted research on using digital technology, collective action participation, and livelihood capital of farm households in China's mining areas. Compared with other regions, there are significant gaps in economic

and social development, digital infrastructure, and livelihoods of farm households in mining areas, making it even more arduous to promote the construction of digital villages and rural revitalization. (3) Most of the studies on the impact of digital technology use and collective action on the livelihoods of farm households are centered on the adoption of production technology, farm household livelihood income, or farm household livelihood mode, and few studies have examined the impact on the livelihood capital of farm households. Given this, this paper constructs a moderated mediation model based on the perspective of sustainable livelihoods, measures the level of livelihood capital and collective action using entropy value method and factor analysis, respectively, and takes the mining farmers as the survey object, and applies hierarchical regression analysis and Bootstrap test to explore further the differences in the constraints on livelihood capital and the impacts of digital technology, to provide scientific evidence and decision-making references to promote the level of livelihood capital of farm households in the underdeveloped areas.

2 Theoretical analysis and research hypotheses

2.1 Digital technology use and livelihood capital for farmers in mining areas

This paper argues that digital technology application enhances and optimizes the traditional livelihood capital of farming households in mining areas, which in turn promotes changes in livelihood outcomes such as the growth of sustainable livelihood capacity of farming households, with the following main mechanisms: firstly, agriculture thrives by combining with digital technology, such as disseminating knowledge about agriculture-related yield enhancement and the introduction of automated agricultural machinery systems, which improves resource endowment and effectively increases agrarian productivity (Walter et al., 2017) and alleviate natural constraints. Second, the multiplier effect of digital technology has dramatically improved the living standards of farmers, relying on the sharing economy and other scenarios to transform the “rigid” assets held by farmers such as houses, land, agricultural machinery, and so on into capital with income, based on which farmers are more willing to upgrade their living conditions (Wang et al., 2023a). Third, using digital technology has further broadened the social network of farmers in mining areas. Farmers use WeChat, TikTok, and other Internet apps to communicate and learn about current affairs, reducing the cost of information communication (Kavada, 2018), and can also use public numbers and government websites to actively contribute to public affairs and exercise their power, which has shaped new social relations, socialization, and the construction of a new rural order (Malik et al., 2022), providing equal opportunities for the maintenance and development of social capital. Fourth, digital technology can improve the construction of a digital credit system in rural financial markets, alleviate the information asymmetry between borrowers and lenders, reduce the difficulty of acquiring financial capital in the decision-making of farmers in the use of digital finance (Chen et al., 2023), enhance the ability and opportunity of low-income farmers to participate in the market (Smidt and Jokonya, 2022), and help farmers to be more flexible to choose livelihood strategies that

suit them, increase their household income and thus promote the growth of financial capital such as savings. Fifth, the use of digital technology empowers human capital accumulation. On the one hand, the popularization of Internet technology can help farmers with a low level of education to learn new production and management knowledge and skills through short videos and other online platforms, which broadens the accumulation of human capital of farmers (Bentley et al., 2019), further improves farmers’ knowledge stock, and strengthens the self-development ability of farmers. On the other hand, fathers’ use of digital technology will enhance their perception of inequality of opportunity, motivating them to increase the human capital cultivation of their offspring, expanding the vision of career choice and employment opportunities for their offspring (Wang et al., 2023b). The emergence of new types of education, such as the online classroom, provides a channel to help their offspring obtain high-quality education, narrowing the education gap between urban and rural areas, and promoting the farmers’ offspring’s educational capital. Based on the above analysis, the first Hypothesis H1 tested in this study is: Digital technology use promotes the level of livelihood capital of farm households in mining areas.

2.2 The mediating role of collective action

The use of digital technology enables farmers in mining areas to participate in collective action. First, digital technology strengthens communication and cooperation among farmers by providing instant and accurate information. Some farmers face high production risks in mining areas due to scattered land, backward infrastructure, and harsh natural conditions. Digital tools (such as WeChat groups, Douyin, agricultural apps, etc.) enable them to easily obtain information such as weather forecasts, market conditions, agricultural policies, and technical guidance (Weiss et al., 2000), improve the communication efficiency and collaboration level among farmers, and enhance their collective action capabilities in agrarian production, disaster warning, and resource sharing. Secondly, digital technology has the advantages of high efficiency, low cost, and timely integration of information and resources (Deichmann et al., 2016), which is particularly suitable for relatively inconvenient transportation areas such as mining areas. It has shown apparent effectiveness in farmers organizing collective procurement, agricultural material distribution, and agricultural product sales, reducing transaction costs, improving organizational flexibility and response speed, and making group coordination more conducive to coping with adverse shocks such as climate change, pests, and diseases. Finally, with the advancement of digital rural construction, some farmers in the mining area began to explore the path of agricultural transformation and upgrading, and tried to develop emerging business formats such as leisure agriculture, agricultural tourism integration, and rural homestays (Li, 2022), which further promoted the farmers’ cognitive transformation towards win-win cooperation, weakened the traditional small farmer logic of “going it alone,” and stimulated the willingness to participate in collective action.

Collective action empowers the livelihood capital of farmers in mining areas. First, in resource-based and poverty-stricken mining areas, farmers can effectively increase the economic output value of their land factors through collective action to develop land transfer and scale management (Markelova and Mwangi, 2010), and promote

the accumulation and sustainable use of natural capital. Second, collective action directly encourages the enhancement and optimization of rural public resource supply (Cao et al., 2020), which not only can effectively attract external material capital to actively influx into the countryside, but also reduce the burden of regular expenditures of mining farmers, accelerate the two-way flow of urban and rural resource factors and optimize the allocation of both rural and urban resources. It not only allows rural areas to absorb advanced production factors and management experience from cities, but also encourages urban resources to find new value-added space supporting rural development, so that rural households in mining areas can increase their material capital and enhance their self-development capacity. Third, farmers rely on their social relations in the process of collective action, actively broaden the space for cooperation, and maintain cooperative relationships, which not only leads to external effects such as market expansion, but also absorbs diversified social forces, enhances the organizational cohesion of villagers (Mhembe and Dube, 2017), and promotes the improvement and enhancement of the relationship between farming communities. Fourth, in terms of financial capital, the collective scale has increased the credit recognition of financial institutions for farmers. Especially in the context of insufficient personal credit and scarce financial resources of small and medium-sized farmers in mining areas, the collective credit mechanism has reduced financial transaction costs and improved farmers' loan availability (Baruah et al., 2022). Moreover, many rural villages have adopted the development method of cooperating with other subjects using collective resources such as equity shares, and village collectives can enjoy guaranteed dividends or even excessive dividend guarantees (Li et al., 2023), thus providing new ideas for enhancing financial capital for rural households. Fifth, the village collective action organizer has a natural advantage in allocating and integrating the limited resources in the countryside and linking the cooperation between enterprises and farmers (Ma and Zhu, 2020), which is more conducive to undertaking many public projects issued by the government and providing more employment opportunities for the surplus labor force, thus helping farmers in mining areas to improve the level of human capital. In addition, collective operation pays more attention to the division of labor and coordination between industrial chains, guides individual farmers to adjust to the needs of the industry, and provides technical training opportunities for farmers (Fischer and Qaim, 2014), so that they are constantly in the position of maximizing their role, helping farmers to effectively connect with smart agriculture and promote the enhancement of human capital level. Based on the above analysis, the second hypothesis H2 tested in this study is: Digital technology use enhances the livelihood capital of mining farmers by facilitating their participation in collective action.

2.3 The moderating role of risk perception

Farmers in mining areas often face a series of risk shocks, such as land destruction, resource depletion, and environmental pollution. Although the occurrence of natural risks is "memoryless," whether or not farmers take risk management measures depends mainly on their risk perceptions shaped by past experiences (Duinen et al., 2015). First, as farmers' perception of risk increases, they may pay more attention to the potential threat posed by social dilemmas, which

triggers more pro-social motives (Zhang et al., 2017), prompting them to take responsive actions to avoid risk. Studies have shown that perceived social risk promotes collective action, while low levels of risk perception limit farmers' adaptive behavior (Zhou et al., 2022). Farmers' acquisition of skills and experience related to digital technology can greatly facilitate farmers' adaptive behavior (Zhang et al., 2020), further promoting collective action. Especially in mining areas, due to the single industrial structure and lack of alternative occupations, farmers' mastery of digital skills and application experience have become an essential guarantee for them to expand their adaptability and participate in collective collaboration.

Second, individual farmers often lack the ability to effectively respond to typical "social dilemma" problems in mining areas, such as difficulty in resource sharing, slow ecological restoration, and lack of public services. In situations of perceived increased risk, access to quality information may become increasingly important (Sligo and Massey, 2007), without which farmers are trapped in an isolated way of life. On the one hand, to avoid risks, rural households are more and more eager to use digital technology to grasp market demand information in time, to alleviate the information asymmetry with the entrepreneurial market, thus reducing market risks (Wang and Cai, 2022). Taking the period of COVID-19 as an example, the stronger the farmers' perception of risk, the stronger their willingness to participate in e-commerce to control the cost of risk and improve the marginal returns (Luo et al., 2024). On the other hand, using digital technology helps farmers join social networks for information, but it also helps strengthen the trusting relationship between them. With an increased level of risk perception, farmers' self-protective impulses usually create a drive towards a stronger sense of shared adversity and establishing a common bond, leading to a higher level of trust (Shi et al., 2023). For example, during a viral pandemic, people's perception of risk motivated them to be more willing to participate in digital contact tracing via mobile apps, increasing acceptance of such initiatives and, in turn, trust in each other (Albrecht et al., 2021). Trust, as a strong predictor of behavior in collective action dilemmas, motivates farm households to show more goal orientation and a sense of responsibility, creating a sense of shared responsibility and collective action (Mullen, 1994). Farmers united as a whole social group will act rationally for the collective good (Ostrom, 2010), which drives them to participate more actively in collective action and face risks and challenges together.

Third, in risky situations, the use of digital technology can strengthen group social capital by increasing the frequency of interaction and expanding the scope of communication. Platforms such as WeChat groups, village affairs disclosure platforms, and digital mutual aid networks not only effectively reduce the cost of information communication among farmers but also continuously strengthen trust and cooperative norms within the group through ongoing interaction, thereby fostering stronger cohesion and a sense of community within the village collective (Wallace et al., 2017). When farmers' risk perception increases, they are more inclined to rely on digital platforms to share resources and risks. This technology-facilitated group trust and cooperative norms are a key manifestation of collective social capital. The accumulation of collective social capital not only provides farmers with a stable cooperative environment and institutionalized guarantees but also lays a solid foundation for larger-scale collaboration and joint action. Based on the above analysis, the third hypothesis H3 tested in this study is: Risk perception has a

positive moderating role in the impact of digital technology use on the collective action participation of mining farmers.

Based on the above analysis, this article further examines the potential moderating role of risk perception in the mechanism by which collective action mediates the use of digital technologies and livelihood capital. Previous research has shown that risk perception not only directly influences individual decision-making but also alters the structural characteristics of their social interactions and willingness to cooperate, thereby influencing the generation of social capital (Wachinger et al., 2013). When farmers have a high level of perception of external risks, they tend to proactively seek external resources and group support to cope with potential uncertainty (Bubeck et al., 2012). In this process, the application of digital technologies strengthens information sharing and resource mutualization among farmers, promoting the formation and sustainability of collective action (Mapiye et al., 2023). Therefore, high levels of risk perception can enhance the positive impact of digital technology application on collective action, enabling farmers to build stronger networks of mutual trust and mutual assistance mechanisms through group collaboration in risky situations, creating favorable conditions for the accumulation of livelihood capital. Conversely, when farmers' risk perception is low, their motivation to withstand external shocks weakens, and the information communication and collaboration capabilities provided by digital technology are less fully utilized (Slovic, 2016). In this scenario, the role of digital technology use in enhancing livelihood capital through collective action is weakened. Based on the above analysis, the fourth hypothesis H4 tested in this study is: The level of risk perception positively moderates the mediating role of collective action between digital technology use and livelihood capital.

Based on the research questions and hypotheses, the specific theoretical model constructed in this paper is shown in Figure 1.

3 Research design

3.1 Data sources

The research data came from a household questionnaire survey conducted in Shanxi Province in May 2023. Focusing on the six major coalfield areas in Shanxi Province, the investigators randomly selected mining areas in Datong City, Taiyuan City, Jinzhong City, Yangquan City, Jincheng City, Linfen City, Yuncheng City, and Changzhi City, covering a total of 56 administrative villages. The survey adopted a

multi-dimensional survey method of “on-site understanding + household interviews + data tracing” to obtain highly authentic and representative first-hand information.

The questionnaire survey adopted a combination of random sampling and key sampling. A total of 350 questionnaires were distributed, and 312 valid questionnaires were collected, with an efficiency of 89.14%. The survey sample covers a wide range of areas, taking into account the differences in different geographical characteristics and regional economic development levels, and is highly representative. From the perspective of individual characteristics, farmers in the mining areas of Shanxi Province are in relatively good health, but have low educational qualifications and are older. From the perspective of family signs, farmers in the mining areas have a small number of laborers engaged in agricultural production, low annual income, and a small actual cultivated land area.

3.2 Selection of variables

3.2.1 Explained variable: livelihood capital

Based on the sustainable livelihood analysis framework, the level of farm household livelihood capital was examined, including natural capital, physical capital, social capital, financial capital, and human capital. Drawing on the research of Dong and Yan (2023) and considering the availability of actual research, 16 indicators were selected to measure the livelihood capital of farm households in mining areas, and the entropy method and linear weighting method were used to calculate the total index of livelihood capital of farm households (Table 1).

3.2.2 Explanatory variable: digital technology use

Most previous studies have examined the use of digital technology from the single dimension of smartphone use or Internet use (Deichmann et al., 2016). Given the increasing popularity and far-reaching impact of digital payment, this paper introduces two more indicators, “whether WeChat or Alipay is bound to a bank card” and “whether online banking (mobile banking) is opened,” and calculates the mean value of the four indicators as the variable of digital technology use.

3.2.3 Mediating variable: collective action

From the three dimensions of participation frequency, participation depth, and value perception, the factor analysis method

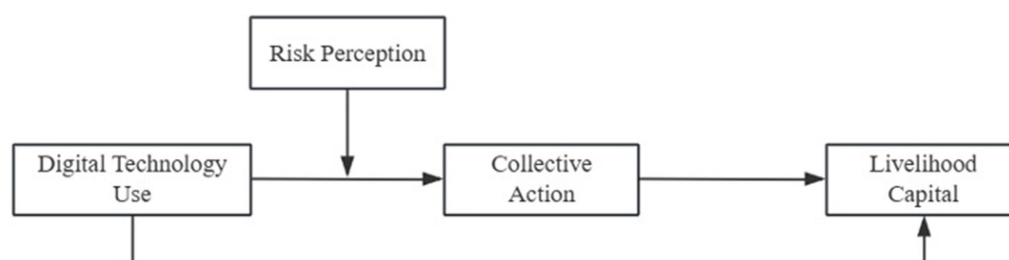


FIGURE 1
Research framework diagram.

TABLE 1 Farm household livelihood capital system and weights.

Type of capital	Measurement indicators	Assignment method	Weights
Natural Capital	Cropland area	Less than 1 acre = 1, 1 to 3 acres = 2, 4 to 6 acres = 3, 7 to 10 acres = 4, 11 acres and above = 5 [Ⓐ]	0.0512
	Forest land area		0.2850
	Homestead area	50m ² and below = 1, 51 ~ 100 m ² = 2, 101 ~ 150 m ² = 3, 151 ~ 200 m ² = 4, 201 m ² and above = 5 [Ⓐ]	0.0240
Physical Capital	House size	50m ² and below = 1, 51 ~ 100 m ² = 2, 101 ~ 150 m ² = 3, 151 ~ 200 m ² = 4, 201 m ² and above = 5	0.0238
	Type of housing	Thatched house = 1, Adobe house = 2, Brick house = 3, Bungalow = 4, Building = 5 [Ⓐ]	0.0066
	Agricultural machinery prices	Less than 20,000 = 1, 20,000–50,000 = 2, 50,000–80,000 = 3, 80,000–100,000 = 4, 100,000 or more = 5	0.1036
Social capital	Whether the relative or friend is a village cadre or a civil servant	No = 0, Yes = 1	0.1752
	Number of people visiting respondents' homes to visit during the Spring Festival	10 households and below = 1, 11–20 households = 2, 21–30 households = 3, 31–50 households = 4, 51 households and above = 5	0.0833
	Amount spent on family gifts in the year	500 and below = 1, 501 ~ 1,000 = 2, 1,001 ~ 3,000 = 3, 3,001 ~ 5,000 = 4, 5,001 and above = 5 [Ⓐ]	0.0262
Financial Capital	Annual household income	Less than 20,000 = 1, 20,000–50,000 = 2, 50,000–80,000 = 3, 80,000–100,000 = 4, 100,000 or more = 5 [Ⓐ]	0.0417
	Amount of financial assets owned		0.0801
	Whether borrowing from relatives or friends	No = 0, Yes = 1	0.0365
Human Capital	The health of family members	Poorest = 1, Poorer = 2, Fair = 3, Better = 4, Best = 5 [Ⓐ]	0.0087
	Skill level of household members engaged in agricultural production.		0.0112
	Skill level of household members in non-agricultural production		0.0171
	Skill level of household members in trading		0.0258

[Ⓐ] Cropland area, forest land area, and homestead area are based on self-reports from farmers: Farmers provided feedback to researchers based on the amount of collectively allocated land.

[Ⓐ]The main difference between a bungalow and a building lies in the number of floors and structure. A bungalow is typically a single-story building without stairs. Bungalows are typically simpler in design and larger in size, suitable for rural areas. Buildings are multi-story structures, each floor typically containing different rooms or units, and are typically used in urban areas.

[Ⓐ],[Ⓐ] Annual household gift money expenditure, annual household income, and financial assets are measured in RMB. [Ⓐ]Family Member Health Status: This survey asks family members about their subjective assessment of their health status, including their daily health, common illnesses, and physical activity levels. Responses range from “Poorest” to “Best,” reflecting different levels of health. Specific descriptions: Poorest: indicates poor health, with the possibility of serious illnesses or long-term health problems that affect quality of life. Poorer: indicates fair health, with minor ailments that occasionally affect daily activities. Fair: indicates normal health, with occasional minor discomfort, but overall good health. Better: This refers to a family member in good health, with few illnesses, and able to carry out daily activities. Best: This refers to a family member in excellent health, with excellent physical condition, no obvious health issues, and able to carry out high-intensity physical activities. Measurement of Family Member Work Skill Level: This measure assesses the overall skill level of family members in various types of work (including agricultural production, non-agricultural production, and trade). The following scoring criteria reflect each family member's technical ability, experience, and professionalism at work. Specific descriptions: Poorest: This indicates a complete lack of relevant skills or experience, and is unable to complete basic work tasks. Poorer: This indicates a family member has some basic skills but lacks in-depth expertise, and may have difficulty completing tasks. Fair: This indicates a family member has some skills and experience, is able to perform general work tasks, and has strong independent work ability. Better: This indicates a family member has strong skills and extensive experience, can complete work efficiently and independently, and can handle complex situations at work. Best: This indicates a family member has a high degree of professional skills, is able to innovate in the relevant field or assume senior responsibilities, and possesses excellent work ability.

was used to comprehensively examine the collective action participation status of farmers (Table 2). The test results showed that the KMO value was 0.825 and significant at a 1% statistical level. The three public factors were extracted using principal component analysis, and the cumulative variance contribution rate reached 76.20%, and the proportion of the variance contribution rate of each public factor to the cumulative variance contribution rate was used as the weight, and the total factor score was calculated to obtain the degree of participation in collective action of farm households.

3.2.4 Moderating variable: risk perception

The stronger farmers' risk perception, the more likely they are to participate in insurance to diversify potential production and business

risks. Therefore, referring to the study of Shi and Yu (2024), the degree of necessity that farmers perceive to participate in insurance is used as a variable of risk perception.

3.2.5 Other control variables

To cover as many other factors as possible affecting the livelihood capital of farming households in mining areas, concerning existing studies (Liu et al., 2023), control variables were selected from the respondents' individual and household characteristics. Individual characteristics include gender, age, education level, and marital status; household characteristics include location, household dependency ratio, and household labor force ratio. The values of the variables and their descriptive statistics are shown in Table 3.

TABLE 2 Farmers' collective action indicator system.

Dimension	Measurement indicators	Assignment method	Factor loading
Frequency of participation	Participation in activities organized by the village council every year	0 Times = 1, 1–3 Times = 2, 4–6 Times = 3, 7–10 Times = 4, 11 Times or More = 5	0.859
	Participation in activities organized by the residents' group every year		0.820
	Annual participation in activities organized by farmers' professional cooperatives		0.792
Depth of participation	Number of days per year that a farmer contributes to various activities organized by the village council	0 Days = 1, 1–5 Days = 2, 6–10 Days = 3, 11–15 Days = 4, 16 Days and above = 5	0.770
	Number of days per year that a farmer devotes to the organization of various activities by the population group (production team).		0.708
	Number of days per year that farmers invest in types of activities organized by farmers' cooperatives		0.776
Perception of value	Access to production and business market information	Very Small = 1, Relatively Small = 2, General = 3, Relatively Large = 4, Very Large = 5	0.747
	Enhancement of production and management skills and levels		0.760
	Protection against production and business losses due to natural disasters or falling prices of agricultural products		0.735
	Expanding revenue sources and increasing the scale of revenue		0.653

3.3 Research methodology

3.3.1 Main effects model

Since the explained variable is represented by the total index of livelihood capital of farmers' households and is a continuous variable, the OLS model is usually used for fitting and estimation of the estimation model with the explained variable as a continuous variable. In order to test whether the use of digital technology can promote the level of livelihood capital of mining farmers, this paper constructs the following model:

$$\text{Livelihood Capital}_i = \alpha_0 + \alpha_1 \text{Digital Technology Use}_i + \alpha_2 \sum \text{control}_i + \varepsilon_i \quad (1)$$

In Equation 1, i denotes an individual farmer, control represents the control variable, α is the coefficient to be estimated, and ε denotes the random error term.

3.3.2 Mediation effects model

Existing literature often utilizes hierarchical regression of mediation models when conducting mechanism analysis. This method, by gradually introducing variables, can clearly reveal the direct effects of independent variables on dependent variables, as well as the indirect effects through mediating variables. The specific steps are as follows: First, control variables are included in the regression equation to eliminate the potential influence of these factors on the dependent variable; second, independent variables are introduced to analyze their direct effects on the dependent variable; and finally, mediating variables are included in the equation to observe whether the influence of the independent variables on the dependent variable changes, as well as the effect of the mediating variables on the dependent variable. If the regression coefficient of the independent

variable decreases and the regression coefficient of the mediating variable is significant, it indicates the presence of a mediation effect, that is, the independent variable affects the dependent variable by influencing the mediating variable. To verify whether the use of digital technology affects the livelihood capital of mining farmers through collective action, this paper adopts the stratified regression method to test the mediating effect of collective action concerning the study of Baron and Kenny (1986). The specific model is set up as follows:

$$\text{Collective Action}_i = \beta_0 + \beta_1 \text{Digital Technology Use}_i + \beta_2 \sum \text{control}_i + \varepsilon_i \quad (2)$$

$$\text{Livelihood Capital}_i = \gamma_0 + \gamma_1 \text{Digital Technology Use}_i + \gamma_2 \text{Collective Action}_i + \gamma_3 \sum \text{control}_i + \varepsilon_i \quad (3)$$

In Equations 2, 3, both β and γ are coefficients to be estimated, and all other variables are consistent with Equation 1.

3.3.3 Moderated effects model

In current academic research, exploring heterogeneity in influencing mechanisms often involves conducting in-depth analysis using interaction-term moderating effect models. This approach, by introducing an interaction term between the independent variable and the moderating variable in the regression equation, examines whether the influence of the independent variable on the dependent variable changes significantly with changes in the level of the moderating variable. Specifically, if the coefficient of the interaction term is significantly nonzero, it indicates a moderating effect—that is, the moderating variable strengthens or weakens the influence of the independent variable on the dependent variable. To examine whether collective action is affected by risk perception in the process of digital technology use promoting livelihood capital among farmers in mining

TABLE 3 Descriptive statistics for variables.

Variable type	Variable name	Description of variables	Mean	Std. Dev.
Explained variable	Livelihood capital	The entropy and linear weighting methods were used to calculate the total index of farm household livelihood capital in Table 1	0.26	0.147
Explanatory variable	Digital technology use	The mean values of the four measures “whether they use smartphones,” “whether they use the Internet,” “whether they have a bank card bound to WeChat or Alipay,” and “whether online banking (mobile banking) is opened”	0.68	0.366
Mediating variable	Collective action	Measured by factor analysis of 3 dimensions: frequency of participation, depth of participation, and perception of value	0	0.609
Moderating variable	Risk perception	The mean value of the necessity to participate in the new rural medical insurance, rural pension insurance, commercial insurance such as medical care for major diseases, and crop insurance	2.87	1.182
Individual control variable	Gender	Male = 1, Female = 0	0.66	0.473
	Age	20–29 = 1, 30–39 = 2, 40–49 = 3, 50–59 = 4, 60–69 = 5, 70 + = 6	3.19	1.278
	Education	Illiteracy = 1, Primary school = 2, Junior high school (technical school) = 3, Senior high school (middle school) = 4, Junior college (high school) = 5, Bachelor's degree = 6, Postgraduate student = 7	3.13	1.258
	Marital	Unmarried = 1, Married = 2, Divorced = 3, Widowed = 4	1.92	0.532
Household control variables	Location	Taiyuan sample = 1, Other regions = 0	0.05	0.227
	Household dependency ratio	Number of persons aged 65 and over/total household size	0.16	0.220
	Household labor force ratio	Number of persons in the family labor force/total number of persons in the family	0.56	0.258

areas, drawing on the study of [Hayes \(2015\)](#), a product term for digital technology use and risk perception was added to the basic regression model to construct a moderating effect model based on interaction terms. The specific model setting is as follows:

$$\text{Collective Action}_i = \delta_0 + \delta_1 \text{Digital Technology Use}_i + \delta_3 \text{Risk Perception}_i + \delta_4 \text{Digital Technology Use}_i \times \text{Risk Perception}_i + \delta_5 \sum \text{control}_i + \varepsilon_i \quad (4)$$

In [Equation 4](#), δ is the coefficient to be estimated, and all other variables are consistent with [Equation 1](#).

3.3.4 Moderated mediation effects model

Drawing on [Preacher et al. \(2007\)](#), this paper adopts the bootstrap method to categorize the moderating variables into two groups, low and high, and to judge the significance of the moderating effects based on the differences in the coefficients of the mediating effects under different groups. The bootstrap method was chosen because it is relatively simple to implement, requiring only repeated random sampling and calculation from the original dataset to simulate the sampling distribution. Furthermore, while the bootstrap method is computationally slower than estimation methods based on the normal distribution assumption, its confidence interval calculations can correct for bias and exhibit asymmetry, eliminating the need for strict assumptions about the distribution of conditional indirect effects. This makes it more flexible and applicable in agricultural production. The specific operation is to use the SPSS macro program PROCESS to construct a 95% confidence interval, perform 5,000 repeated samplings, and obtain the conditional

indirect effect of digital technology use on the livelihood capital of farmers in mining areas through collective action under different values of risk perception, so as to judge whether the model is established.

4 Results and analyses

4.1 Hypothesis testing

4.1.1 Main effects test

The research hypotheses presented in this paper are tested using cascade regression, and the results are shown in [Table 4](#). Model 1 in [Table 4](#) is the regression result with the control variables of this paper as independent variables, and Model 2 is the regression result after adding digital technology use to Model 1. The results of the analysis of Model 2 show that digital technology use has a significant positive impact on the livelihood capital of mining farmers ($\beta = 0.177$, $p < 0.01$), and H1 is verified. That is, the use of digital technology can effectively improve farmers' ability to obtain and utilize various livelihood resources, systematically enhance their multidimensional livelihood capital, and thus promote the improvement of their sustainable livelihood capabilities.

4.1.2 Mediation effects test

According to Model 5 in [Table 4](#), digital technology use significantly and positively affects the level of participation in collective action ($\beta = 0.555$, $p < 0.01$); from Model 3, collective action significantly and positively impacts the livelihood capital of farmers in the mining area ($\beta = 0.106$, $p < 0.01$); and from Models 2 and 4 it can be seen that the regression coefficient between digital

TABLE 4 Cascade regression results.

Variables	Livelihood capital				Collective action	
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Digital technology use		0.177*** (0.020)		0.132*** (0.020)	0.555*** (0.090)	0.356*** (0.068)
Risk perception						0.363*** (0.021)
Digital technology use * risk perception						0.135*** (0.054)
Collective action			0.106*** (0.012)	0.080*** (0.012)		
R ²	0.078	0.260	0.262	0.352	0.136	0.587
F	4.739	14.642	14.808	19.780	7.101	42.828

Parentheses indicate robust standard deviations; *, **, and *** indicate significance at the 10, 5, and 1% levels, respectively. The following table is the same.

technology use and the level of livelihood capital decreased from 0.177 to 0.132 after the inclusion of collective action and remained significant ($\beta = 0.132$, $p < 0.01$). This suggests that collective action partially mediates the relationship between digital technology use and the livelihood capital of mining farmers, and H2 is tentatively validated. To ensure the robustness and consistency of the mediating effect of collective action between digital technology use and livelihood capital of mining farm households, this paper applies Bootstrap to sample 5,000 replications. The results in Table 5 show that the value of the indirect effect of digital technology use affecting livelihood capital through collective action is 0.044, with a 95% confidence interval of [0.025, 0.067] excluding zero, which further suggests that collective action plays a partially mediating role between digital technology use and livelihood capital of farm households in mining areas, and hypothesis 2 is further supported. Meanwhile, the Sobel test found that the value of the Z-statistic was 4.53, and the mediating effect accounted for 25.08% of the total effect.

4.1.3 Moderated effects and mediated effects test with moderation

To reduce the effect of multicollinearity, all continuous variables were centered. The results of model 6 show that the regression coefficient of the interaction term of digital technology use and risk perception is significant ($\beta = 0.135$, $p < 0.05$), indicating that the degree of risk perceived by farmers positively moderates the relationship between digital technology use and collective action, and H3 is verified. To observe its moderating effect more intuitively, this paper classifies risk perception into two categories of high and low according to adding or subtracting one standard deviation and plots the interaction effect as shown in Figure 2. The simple slope test shows that under high risk perception conditions, the impact of digital technology use on collective action is stronger, while under low risk perception conditions, the effect is more moderate. That is, when farmers perceive a high level of risk, their level of digital technology use has a stronger effect on promoting collective action, and they are more inclined to seek collective cooperation through digital means, thereby enhancing their ability to act.

To test hypothesis 4, this paper uses Bootstrap for 5,000 replicated samples, which is used to estimate the magnitude of the mediating effect of collective action between digital technology use and livelihood capital of mining farmers under different risk perceptions. The test results in Table 6 show that the impact of this indirect effect is more significant

TABLE 5 Bootstrap mediation affects test results.

Type of effect	Estimated value	SE value	Boot LLCI	Boot ULCI
Direct effect	0.132	0.020	0.092	0.172
Indirect effect	0.044	0.011	0.025	0.067
Total effect	0.177	0.020	0.137	0.216

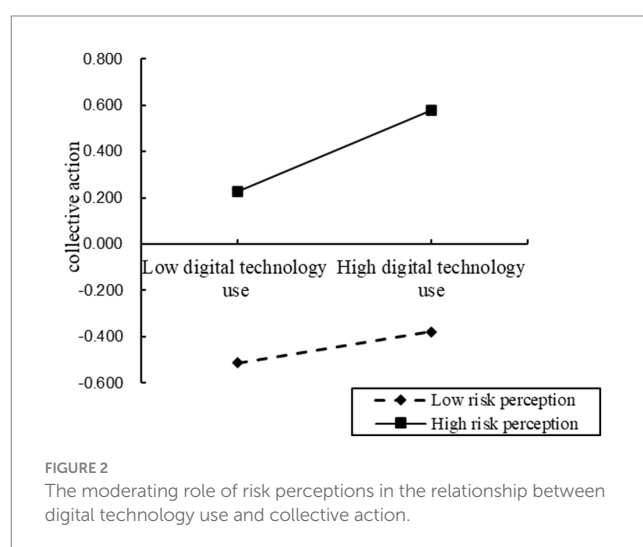


FIGURE 2

The moderating role of risk perceptions in the relationship between digital technology use and collective action.

when the level of risk perception is high (Effect = 0.041, Boot SE = 0.013, 95% CI = [0.019, 0.071]). The indirect effect of digital technology use affecting farmers' livelihood capital through collective action was significant when the level of risk perception was low (Effect = 0.016, Boot SE = 0.006, 95% CI = [0.004, 0.028]); furthermore, the value of the difference between the indirect effect at high and low-risk perception was 0.011, with a 95% confidence interval of [0.001, 0.023], excluding zeros, H4 was validated.

4.2 Robustness tests

4.2.1 Replacement of explanatory variables

The frequency of using WeChat Pay is selected, and the variable is comprehensively classified as a binary variable, and "often use" and

TABLE 6 Results of the regulated mediation test.

Risk perception	Mediating effects: digital technology use → collective action → livelihood capital			
	Boot indirect effect	Boot SE	5,000 Bootstrap (95% confidence interval)	
			LLCI	ULCI
Low level of risk perception	0.016	0.006	0.004	0.028
High level of risk perception	0.041	0.013	0.019	0.071
Differences in indirect effects	0.011	0.006	0.001	0.023

TABLE 7 Robustness test regression results.

Variables	Replacement of explanatory variables	Instrumental variable approach		Propensity score matching method
	Livelihood capital	First phase (explained variable: digital technology use)	Second phase (explained variable: livelihood capital)	Livelihood capital
The average level of digital technology use among other farmers in the same village		0.156*** (0.030)		
Digital technology use	0.106*** (0.023)		0.561*** (0.103)	0.164*** (0.011)
Control variables	Yes	Yes	Yes	Yes
Constant	−0.051 (0.062)	0.486** (0.081)	−0.094 (0.089)	−1.172 (1.251)
R2	0.137	0.162	-	0.065
F-statistic	7.172	7.980	4.915	

Parentheses indicate robust standard deviations; *** indicate significance at the 1% level, respectively.

“occasionally use” are comprehensively classified as “use” and assigned as “1,” and “do not use/will not use/do not know” is classified as “do not use” and designated as “0,” and the empirical test is carried out. The regression results are shown in column 1 of Table 7, again confirming H1.

4.2.2 Instrumental variable approach

Drawing on Gao et al. (2020), the mean level of digital technology use by other farmers in the same village is selected as the instrumental variable to further deal with possible endogeneity issues. The reason for this is that, on the one hand, respondent farmers can enhance their motivation to adopt digital technologies by borrowing experiences from neighboring farmers; on the other hand, the level of digital technology adoption by other farmers is seen as a completely exogenous factor compared to the respondent's livelihood capital status. Table 7 reports the results of the two-stage regression of instrumental variables; the first stage results show significantly positive coefficients for the average level of digital technology use among other farmers in the same village, verifying that the instrumental variables satisfy the correlation and the F-statistic is 7.980, ruling out the problem of weakly correlated variables. The fitted coefficient of digital technology use in the second stage is positive at the 1% statistical level, which is consistent with the baseline regression results, confirming that the use of digital technology can increase the level of livelihood capital of farmers in mining areas.

4.2.3 Propensity score matching method

To mitigate the problems of omitted variables and selectivity bias, this paper draws on the study of Wang et al. (2019) where mining

farmers who do not use digital technology are used as a control group for propensity score matching using a 1:1 nearest-neighbor matching method. The result, as shown in column 4 of Table 7, shows that the coefficient of digital technology use on livelihood capital is significantly positive, suggesting that digital technology use can still contribute to the livelihood capital of mining farmers after matching.

4.3 Heterogeneity analysis

4.3.1 Gender characteristics

To explore in depth whether there are gender differences in the impact of digital technology use on the livelihood capital of mining farmers, the paper regresses the sample into female and male groups. The results in columns 1 and 2 of Table 8 show that digital technology use enhances livelihood capital for both men and women. Further comparative analysis reveals that the male group's livelihood capital is more significantly boosted by digital technology. There are complex socio-economic factors behind this phenomenon. In terms of the economic structure of the family, men tend to occupy a dominant position in the family, taking on more responsibility for financial decision-making and access to resources. The spread of digital technology has opened up broader channels for men to access and utilize resources, thus contributing more effectively to the accumulation of livelihood capital. In contrast, rural women in the past may be more responsible for household chores and children's education in the family, and relatively limited in the use of digital technology in the time and energy investment, although the digital

TABLE 8 Heterogeneity test regression results.

Variables	Female group	Male group	Middle-aged and youth group	Old age group
Digital technology use	0.133*** (0.031)	0.198*** (0.026)	0.166*** (0.022)	0.249*** (0.057)
Constant	−0.014 (0.085)	−0.006 (0.071)	0.048 (0.058)	−0.008 (0.121)
Control variables	Yes	Yes	Yes	Yes
Observes	105	207	267	45
R ²	0.139	0.275	0.207	0.490

Parentheses indicate robust standard deviations; *** indicate significance at the 1% level, respectively.

technology also brings them convenience, but in the promotion of livelihood capital to promote the strength of a little less. In addition, socio-cultural factors also affect to a certain extent the empowering effect of digital technology on the livelihood capital of farmers of different genders. Traditionally, men tend to be given higher expectations and support for technology learning and application, which may give them an advantage in digital technology learning and application, enabling them to tap the potential of digital technology more fully, thus realizing faster growth of livelihood capital.

4.3.2 Age characteristics

Does the issue of digital disempowerment affect the fulfillment of the empowering effect of digital technology due to the aging trend of mining farmers? This paper tests this by dividing the sample into a young and middle-aged group of 20–59 years old and an older group of 60 and above. Columns 3 and 4 in Table 8 reveal that digital technology use has a more significant enhancement effect on the livelihood capital of the older group compared to the young and middle-aged groups. The possible reasons are as follows: firstly, the rise of social software has brought new opportunities for expanding the social network of older people. Traditional social networks are often limited to geographic and blood relations, while social software breaks this limitation, enabling older people to cross the geographical boundaries, meet more like-minded friends, and expand their social circles. This expansion of social networks not only enriches the spiritual life of older people but also provides them with more opportunities for information exchange and resource sharing, which promotes the integration of older people into the digital society and thus enhances their livelihood capital. Secondly, flexible and convenient curriculum resources provide an effective way to break the cognitive limitations of the digital divide for older people who face the risk of being eliminated from the market. Older people may face many difficulties learning and applying digital technologies as they age, but today's rich online course resources allow them to learn anytime, anywhere. Through these courses, older people can master basic digital skills, such as using smartphones, online shopping, online payment, etc., thus breaking the cognitive limitations imposed by the digital divide and enriching their human capital through barrier-free access to information. Once again, as young and middle-aged farmers are in the developmental stage of their lives, their material and natural capitals are primarily dependent on the support of their parents and grandparents, which is still weak. In this case, although digital technology provides them with opportunities to access information and expand markets, the direct impact of digital technology on their livelihood capital is still limited due to the lack of sufficient material foundation and resource

accumulation. Finally, digital technology can positively impact the “long tail” groups in society, of which the elderly population is a typical example. With the development of digital technology, the threshold of access to financial services and other products has been lowered, and the elderly population can enjoy financial services more conveniently, such as online financial management and mobile payment. This not only facilitates the continued shift of financial capital to the elderly population but also provides them with more investment opportunities, demonstrating the potential of digital technology to empower disadvantaged groups positively.

5 Further analyses

5.1 Impact of different digital technology use purposes and frequency of use on livelihood capital of farming households in mining areas

As Internet penetration climbs and farmers' access to digital technologies increases significantly, the purpose and frequency of technology use need to be explored more to reveal its multidimensional impact on farmers' livelihood capital fully. In this paper, out of 312 valid samples, 264 farm households with digital technology use behaviors were selected as the analysis target. The role of representative purposes of digital technology use (e.g., online shopping, leisure and entertainment, and online business) and their frequency of use (Luo and Liu, 2022) on the livelihood capital of farm households was explored in depth.

The results in Table 9 show that the frequency of online shopping, leisure and entertainment, and online commerce among farmers all significantly positively affect the growth of farmers' livelihood capital. This indicates that online shopping not only enriches farmers' shopping choices, realizes the leap from limited offline comparisons to unlimited online comparisons, and reduces consumption costs; online business significantly broadens farmers' market boundaries, enhances their ability to obtain external resources, and thus effectively improves operating income; and online leisure and recreation meets the spiritual needs of farmers, promotes the accumulation of social capital and social rights, further enriching farmers' social network and spiritual world. It is worth noting that the frequency of online business activities has the most prominent positive effect on farmers' livelihood capital, suggesting that digital technologies aimed at “capital accumulation” have more potential and efficiency in promoting farmers' livelihood capital growth than pure entertainment.

TABLE 9 Impact of differences in the purpose and frequency of use of digital technologies.

Variables	Livelihood capital	Livelihood capital	Livelihood capital
Frequency of online shopping	0.070*** (0.011)		
Frequency of leisure and recreation		0.068*** (0.012)	
Frequency of online business			0.071*** (0.014)
Constant	−0.054 (0.067)	−0.020 (0.067)	0.022 (0.067)
Control variables	Yes	Yes	Yes
R ²	0.197	0.167	0.139

The frequency of digital technology use is measured by respondents' answers to the questionnaire "How often do you use the Internet for the following activities," with "Not at all/do not know/will not use" assigned a value of 1; "Occasionally use" assigned a value of 2; and "Often use" assigned a value of 3. Parentheses indicate robust standard deviations; *** indicate significance at the 1% level, respectively.

TABLE 10 Impact of differences in the level of use of digital technology.

Variables	Livelihood capital	Livelihood capital
The average monthly cost of mobile phone service for household members	0.064*** (0.010)	
Whether family members are involved in online shopping activities		0.088*** (0.019)
Constant	−0.085 (0.061)	−0.010 (0.060)
Observes	312	312
Control variables	Yes	Yes
R ²	0.186	0.135

Parentheses indicate robust standard deviations; *** indicate significance at the 1% level, respectively.

5.2 Impact of different levels of digital technology use on livelihood capital of farming households in mining areas

In examining the complex relationship between the impact of different levels of digital technology use on the livelihood capital of mining households, this paper selects two key indicators: first, the average monthly mobile phone service cost of household members, and second, whether or not household members participate in online shopping activities. The cost of mobile phone service includes the number of call minutes and the amount of SMS and data traffic, which not only meets farmers' basic communication and social needs but also indirectly maps the acceptance and dependence of farmers on digital technology. Online shopping, as an internet activity that covers high-skill requirements such as active information search, real-name authentication, and electronic payment, is regarded as an effective yardstick to measure the deep use of digital technology, which helps to assess whether deep digital use can bring better capital growth effects for farmers.

Table 10 reports the regression results. First, the coefficient on the regression of average monthly mobile phone service costs of household members on livelihood capital is smaller than on digital technology use. Digital technology use leads to a 17.7 percent increase in capital for farm households in mining areas, far exceeding the capital growth associated with increased mobile phone service costs for household members and online shopping behavior. This suggests that Internet access itself is a strong driver of livelihood capital. On top of that, while increased service fees and online shopping help to further stimulate the capital appreciation potential of farmers, their marginal effects are also decreasing given the economic constraints faced by farmers in the mining areas, suggesting that the government

needs to pay attention to the financial viability and sustainability of the use of digital technology.

6 Discussion

As a country rich in mineral resources, China's mining areas are widely distributed in rural areas with fragile livelihood conditions and lagging levels of economic development, and these areas are often closely linked to the living spaces of farming households (Niu et al., 2022). Therefore, finding a balance between mineral resource development, the sustainable livelihoods of farmers, and ecological protection has become a significant challenge for sustainable rural development around mining areas. This paper takes Shanxi Province, the wealthiest province in coal resources, as the study area, and finds that although the farming households in the mining areas have escaped from poverty, the accumulation of livelihood capital is still weak. It is easy for them to return to poverty again. There are several reasons for this: first, the destruction of ecosystems has caused large-scale damage to farmland and arable land, and although the high density of ecological restoration policies in mining areas has produced significant effects, it takes time to re-establish vegetation and improve the soil (Hu et al., 2020). Second, for provinces still highly dependent on resource exports, such as Shanxi, a strong link between the rural and mining economies is critical to maintaining sustainable livelihoods for residents. Given the relatively limited number of livelihood strategies people can rely on, a green transition is unlikely to happen overnight.

Existing literature has examined the impact of mining development on the livelihood capacity of farming households from multiple perspectives. First, some studies have focused on how mining

influences farmers' choices of livelihood strategies in mining areas. In their research in Sierra Leone, [Maconachie and Binns \(2007\)](#) revealed a dynamic equilibrium mechanism between the mining and agricultural sectors. They found that farming households, constrained by limited resources, adopted a combined strategy of seasonal crop rotation and temporary mine employment to reallocate their livelihood capital spatially, thereby contributing to the rebuilding of the rural economy. Similarly, [Balasha and Peša \(2023\)](#), in their research on the Katanga Copper Belt, observed that mining activities spurred spontaneous population agglomerations around mining zones, subsequently giving rise to informal trade networks. These networks enabled farmers to buffer the loss of arable land caused by mining through short-chain marketing strategies that directly supplied goods to miners. Second, other studies approach the issue from the perspective of the conflict between resource extraction and ecological conservation. For example, [Gokalp and Mohammed \(2019\)](#) identified mining as a major source of heavy metal contamination in soil. This contamination leads to land degradation and poses serious risks to human health through the food chain and other pathways. [Muimba-Kankolongo et al. \(2022\)](#) similarly highlighted the destructive effects of mining on the agro-ecological environment, noting that extractive industries impact both soil and water sources used by farmers. Crops grown in contaminated soil experience reduced growth, performance, and yield, resulting in poor harvests and food shortages. Third, scholars have also explored the competitive relationship between mining and agriculture regarding resource allocation. [Binns \(1982\)](#), using a case study of diamond mining regions in Africa, found that the labor-siphoning effect triggered by the mining boom disrupted local agricultural systems, as the outmigration of young laborers weakened the region's capacity for food self-sufficiency. [Worlanyo et al. \(2022\)](#), studying gold mining in Ghana, pointed out that the spatial expansion of mining land leads to agricultural land compression, posing a significant threat to agricultural production and undermining the sustainable income sources of farming households. More recently, research on mining regions in China has shifted toward the adaptive responses of farmers. For instance, [Zhou et al. \(2022\)](#) investigated the mining area of Daye City, Hubei Province, and found that farmland contamination by heavy metals, coupled with limited knowledge and information, hinders farmers from effectively adopting adaptation measures. Building on this, the present study examines how farmers in such contexts can enhance their livelihood capital and whether digital village initiatives can offer new pathways for development.

This paper further explores the delicate balance between farmland cultivation and mining development. Agricultural activities cannot be sacrificed entirely to halt mining operations. Meanwhile, the large-scale relocation of farmers to other regions faces numerous practical obstacles and is mainly unfeasible. In this context, digital technology holds great potential to optimize both the mining process and the development trajectory of farmers. During the pre-mining phase, the specialized application of digital tools demonstrates significant advantages. For instance, 3D radar point cloud imaging can construct real-time three-dimensional surface models of mining areas, providing accurate data for mine planning. This not only minimizes encroachment on farmland but also supports the sustainability of agricultural production ([Chen et al., 2024](#)). During mining operations, digital technologies play a vital role in environmental regulation. With their assistance, a data-sharing and monitoring platform for industrial

pollution indicators, such as trace heavy metal concentrations, can enable comprehensive and dynamic pollution monitoring, thereby reducing environmental risks ([Lv and Ding, 2024](#)). In the post-mining phase, digital ecological restoration technologies have matured considerably. Precision soil remediation enables tailored treatment plans based on contamination levels; water ecosystem restoration aims to recover aquatic systems' self-purification capacity and ecological balance; and scientifically planned vegetation restoration accelerates ecosystem recovery. Integrating these technologies can effectively repair environmental damage caused by mining activities and mitigate long-term losses ([Sun, 2024](#)). Farmers, as primary users of farmland and key actors in food security, play a crucial role in the agroecosystem. Understanding their perceptions of mining-related pollution is essential for addressing environmental challenges such as heavy metal contamination ([Zhou et al., 2022](#)). Digital technologies offer accessible platforms for farmers to acquire knowledge, stay informed about the ecological impacts of mining, and learn relevant countermeasures. Furthermore, these technologies facilitate communication between farmers and government authorities, enabling farmers to voice their concerns and contribute suggestions. Such interactions foster cooperation and jointly promote the sustainable development of mining regions.

The popularization and application of digital technology often require specific cost inputs, including the purchase of equipment and skills training, etc., which constitutes a greater economic pressure on farmers in mining areas with relatively poor economic conditions. At the same time, farm households cannot master emerging digital technologies due to education, age, and traditional thinking limitations ([Odini, 2014](#)). Nonetheless, this paper still argues that in the context of digital village construction, farm households' development prospects for using digital technologies are broad. By introducing a series of policies and expanding technology coverage, farm households can enjoy a more convenient and low-cost environment for learning and applying digital technology, thus enhancing their livelihood capacity and living conditions. In addition, the frequency and extent of digital technology use positively impact rural residents' livelihood capital. Although some studies have shown that excessive use of digital technology for entertainment may lead to problems such as online pan-entertainment and Internet addiction ([Young et al., 2019](#)), which in turn reduces livelihood capacity, survey data show that the frequency of digital technology use by rural households in China's mining areas is relatively low and has not reached the level of excessiveness. On the contrary, digital technology has brought practical benefits to rural residents by enabling them to access production and business information, learn skills, receive government services, and participate in government supervision in a timely and convenient manner. For example, the contribution of digital technology to the livelihood capital of rural households is particularly prominent in the older group than in the middle-aged and younger groups. That is, access to the Internet for the "disadvantaged" not only helps to improve the plight of older people who have "nothing to rely on" ([Hill et al., 2015](#)) and enrich their recreational life ([Siegel and Dorner, 2017](#)), but also encourages them to pursue a proactive approach to their livelihoods ([Li et al., 2025](#)). For the majority of mining villagers, the ability of rural residents to use online information should be improved, and rural residents should be differentially guided to actively use digital technology, such as increasing the frequency of digital technology use in business activities.

Next, this paper attempts to contextualize its main research findings within the framework of classical collective action theory:

First, regarding the conclusion that digital technology promotes collective action, according to [Olson's \(1971\)](#) view of collective action, individuals in large groups often lack the motivation to actively participate in collective action due to high coordination costs and the prevalence of free-riding, unless selective incentive mechanisms are in place. This paper's results show that the introduction of digital technology reduces the costs of information collection and communication, lowering farmers' coordination costs in collective procurement, disaster response, and market access, effectively providing a new form of "incentive." Furthermore, the application of digital technology improves information transparency and process traceability, providing new tools for oversight and regulation. For example, in agricultural input procurement, revenue distribution, or public affairs negotiations, farmers can access real-time information on fund flows, task progress, and member contributions through WeChat groups, online public information platforms, or agricultural apps, thereby reducing information asymmetry and diminishing the scope for opportunistic behavior. This is highly consistent with Olson's proposition of "reducing the costs of collective action," demonstrating that digital tools can overcome the traditional dilemma of collective action in resource-constrained settings. From another perspective, [Ostrom \(1990\)](#) argues that public affairs management mechanisms are not limited to government or market approaches, but rather multiple possibilities, critically depending on management effectiveness, benefits, and fairness. This paper finds that, first, digital technology improves information symmetry and communication efficiency, reducing farmers' concerns about "uncertainty" and "free riding" in cooperation, thereby enhancing trust in cooperation and willingness to coordinate. Second, digital platforms demonstrate low cost and high efficiency in resource integration, helping to alleviate the structural barriers of poor transportation and dispersed resources in mining areas and significantly reducing the organizational costs of collective action. Third, as farmers frequently interact on digital platforms, they gradually internalize the values of shared development and win-win cooperation. These mechanisms demonstrate that digital technology can enhance the possibility and sustainability of farmers' collective action through the three pathways of information, resources, and cognition, thereby confirming the institutional value of technological factors within a multi-faceted governance model.

Second, we examine the role of collective action in enhancing farmers' livelihood capital in mining areas. On the one hand, through self-organization and rule-based constraints, farmers collectively accumulate and manage natural, social, and human capital, achieving collective outcomes that transcend individual capabilities. This model emphasizes endogenous cooperative motivations and community cohesion, aligning with the concepts of polycentric governance and community self-governance. On the other hand, practices such as using collective credit to enhance the availability of financial capital, promoting scale operations through land transfer, and obtaining dividends through equity cooperation rely more heavily on the external integration of market-oriented logic and institutional arrangements, highlighting efficiency and economic benefits. Therefore, it can be argued that the collective action of farmers in mining areas does not simply remain at the level of community

autonomy, but rather lies within a process of intertwined "community co-governance and market-driven development." Its outcomes embody both the self-governance of public affairs emphasized by Ostrom and the distinct attributes of market-based cooperation.

Third, the role of risk perception in promoting the relationship between digital technology use and collective action may encompass two logics. Initially, farmers in mining areas often adopt a passive approach to risk shocks, relying on digital technology and group collaboration driven by loss aversion and self-protection, thereby passively moving towards prosocial behavior. This aligns with the concept of "risk-driven passive adaptation" emphasized in behavioral economics. However, as interactions increased and trust gradually built, collective action ceased to be simply an emergency response to risk situations and gradually evolved into a cooperative mechanism with endogenous motivations. During this phase, Ostrom's view that "adversity fosters cohesion" was more fully embodied: risk pressures in turn stimulated higher levels of trust and a sense of community among community members, thereby driving farmers' sustained participation in collective action. This shift from "passive adaptation" to "active cohesion" reveals the dual role that risk perception can play at different stages of development.

Finally, this paper will conduct an in-depth analysis of the goodness of fit of the constructed models. The R^2 coefficients of the main models all exceeded 0.13. In the field of socioeconomic research based on household survey data, this level is considered reasonable and has a certain degree of explanatory power. The livelihood capital of farmers in mining areas is influenced by multiple factors, including natural endowments, social networks, family characteristics, and the policy environment. However, this study focuses on the mechanisms through which digital technology use and collective action influence livelihood capital. Because it is difficult to comprehensively cover all influencing factors, the explanatory power of the model is relatively limited. Furthermore, farmers exhibit significant individual differences in digital technology application capabilities, social participation, and risk perception, which to some extent affects the overall goodness of fit of the model. This study focuses on identifying the interaction pathways and mechanisms between variables. The direction and significance of the coefficients of the main variables remain consistent across different model settings, indicating that the conclusion that digital technology use significantly enhances farmers' livelihood capital through collective action is robust and has realistic explanatory power.

7 Conclusions and implications

Based on the micro-survey data of 312 farmers in mining areas in Shanxi Province, an underdeveloped area, the livelihood effects of farmers' use of digital technology in the process of digital village construction were investigated and analyzed. The results show that: first, the use of digital technology helps to improve the level of farmers' livelihood capital. Compared with farmers who do not use digital technology, the level of farmers who use digital technology is 0.177 units higher. Second, collective action plays a partial mediating role in the path relationship between the use of digital technology and farmers' livelihood capital, and the mediating effect accounts for 25.08% of the total effect. Third, risk perception can positively regulate the relationship between the use of digital technology and collective action, and affect farmers' livelihood capital through collective action.

Fourth, the sub-sample study found that the use of digital technology has a more significant positive effect on the livelihood capital of farmers in the male group and the elderly group. Fifth, there is a significant positive correlation between the frequency of digital technology use of farmers in mining areas and the accumulation of livelihood capital. Specifically, farmers' high-frequency participation in online shopping, leisure and entertainment, and online business significantly promoted the appreciation of their livelihood capital, with coefficients of 0.070, 0.068 and 0.071, respectively. Sixth, as the use of digital technology deepens, its positive impact on farmers' livelihood capital continues to exist, but this promotion effect shows a marginal decreasing trend. On the basis that farmers' households have access to the Internet, further increasing mobile phone service expenses and online shopping behavior can still bring incremental livelihood capital, but this growth effect is gradually weakening. Based on the research conclusions of this paper, the following insights can be obtained.

First, digital skills training for farmers in mining areas should be carried out according to local conditions to improve their adaptability and management level. The government should work with mining enterprises, agricultural cooperatives and other entities to set up digital skills training courses specifically for farmers in mining areas. The course content covers practical application skills such as e-commerce sales of agricultural products, short video marketing, and digital operation of agricultural equipment. The training schedule should fully consider the characteristics of labor in mining areas, and flexibly adopt forms such as "night school + online + mobile classroom" to improve participation and effectiveness. At the same time, a reward mechanism for "pioneer farmers in digitalization in mining areas" will be established to provide outstanding farmers with financial subsidies, equipment support or tax exemptions to encourage them to take the lead in exploring diversified ways to increase income in resource-based areas. Second, strengthen the organizational and collaborative capabilities of farmers in mining areas and promote "cooperation to resist risks and collective development." Relying on existing agricultural organizations or new rural collective economic organizations around mining areas, farmers' understanding and trust in cooperatives and joint planting and breeding models will be enhanced through special training, case publicity, demonstration and guidance. The government should provide financial subsidies, tax exemptions and infrastructure support for agricultural communities formed by farmers in mining areas, encourage farmers in marginal areas of mining areas to share resources and make centralized investments, improve production efficiency and market bargaining power, and break the limitation of fighting alone. Third, build a digital information platform exclusively for farmers in mining areas to achieve resource sharing and intelligent management. The government can take the lead in developing an agricultural information service platform exclusively for farmers in mining areas, providing accurate information such as regional market prices, agricultural meteorological warnings, and pest and disease control. The platform can also set up functions such as "agricultural technical questions and answers" and "farmer mutual assistance circles" to facilitate experience exchange and knowledge sharing. Farmers in mining areas who use intelligent agricultural machinery, drone plant protection systems, and precision planting management software will be given purchase subsidies or technical support to promote the development of

agriculture in the direction of intelligence and greening, and improve the quality and benefits of ecological agriculture in mining areas. Fourth, focus on the return of talents in mining areas and build a talent revitalization model of "mining areas + universities + scientific research." Promote mining areas to carry out co-construction projects with universities and agricultural research institutes, establish a "mining area digital agriculture experimental base," and attract teachers and students of relevant majors to go deep into mining areas for field services. Establish exclusive incentive mechanisms, such as providing targeted entrepreneurship subsidies, housing security and professional title evaluation benefits for college students and technicians who return to their hometowns to start businesses, to attract more talents to inject intellectual and technical resources into the digital transformation of agriculture in mining areas, and to create a professional, young and long-term stable local talent team. Fifth, open up the "last mile" of digital infrastructure in mining areas to ensure full access for vulnerable groups. In view of the communication characteristics of mining areas with many mountains, tunnels and blind spots, the government should accelerate the construction of communication base stations and fiber optic networks, especially in remote villages in mining areas and areas where laid-off miners live, to strengthen digital infrastructure investment. And coordinate operators to introduce "mining area care packages" to provide preferential network rates for low-income farmers, left-behind elderly people, etc. Simultaneously carry out digital literacy public welfare courses and practical APP operation guidance to improve the information application capabilities of marginal groups and truly achieve "no one left behind" digital inclusion.

This study has several limitations that warrant further exploration in future research. First, due to constraints in data accessibility, the study focuses on mining households in Shanxi Province. While the sample possesses a degree of representativeness, its size remains limited. Given the substantial heterogeneity in farmers' conditions and digital infrastructure across different regions and resource endowments, future research should aim to expand the sample size and geographic coverage to improve the scientific rigor and generalizability of the findings. Second, although this study centers on the potential of digital technologies to enhance the livelihood capital of mining households, livelihoods are inherently multidimensional, encompassing aspects such as income, strategies, and risk. Therefore, subsequent research should adopt a more comprehensive perspective, exploring these various dimensions to understand the characteristics better and influencing factors of rural livelihoods. Third, the impact of digital technology on livelihood capital is likely influenced by a range of external factors not addressed in this study, such as infrastructure improvements, shifts in economic policy, and the pace of technological advancement. Future studies should incorporate a broader array of mediating and moderating variables to gain deeper insights into the underlying mechanisms, allowing for a more nuanced analysis of how digital technology interacts with various contextual influences. Finally, the reliance on cross-sectional data limits this study's ability to capture the dynamic evolution of digital technology adoption and its long-term effects on livelihood outcomes. Future research should adopt longitudinal designs to monitor changes over time, offering more robust and actionable insights into how digital transformation can sustainably impact the economic development of mining-area households.

Data availability statement

The original contributions presented in the study are included in the article/[Supplementary material](#), further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Taiyuan University of Technology. 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

XH: Conceptualization, Funding acquisition, Investigation, Supervision, Writing – review & editing. JW: Conceptualization, Data curation, Formal analysis, Methodology, Software, Validation, Visualization, Writing – original draft. YW: Data curation, Project administration, Validation, Writing – review & editing.

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Supplementary material

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