frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 13 January 2026
DOI 10.3389/fsufs.2025.1759687

OPEN ACCESS

EDITED BY
Chaozheng Zhang,
Hunan Agricultural University, China

REVIEWED BY
Kai Gan,
Northwest A&F University, China
Haotian Cheng,
Southwest University, China

*CORRESPONDENCE
Xinran Zhou
jcoyotes2020@gmail.com

RECEIVED 03 December 2025
REVISED 20 December 2025
ACCEPTED 25 December 2025
PUBLISHED 13 January 2026

CITATION
Wang J, Song C, Jiang J, Wang Y and Zhou X (2026) Digital payment and the formalization of rural household finance: evidence from landholding households in China.
Front. Sustain. Food Syst. 9:1759687.
doi: 10.3389/fsufs.2025.1759687

Digital payment and the formalization of rural household finance: evidence from landholding households in China

Jingbin Wang[1], Changyang Song[2], Jiejie Jiang[1], Yiqin Wang[3] and Xinran Zhou[4]*

[1]College of Economics and Management, Huazhong Agricultural University, Wuhan, China, [2]School of Management, Qufu Normal University, Rizhao, China, [3]School of Economics, Qufu Normal University, Rizhao, China, [4]College of Open Education, Tangshan Open University, Tangshan, China

Introduction: Developing modern agriculture and improving arable land allocation depend on financial support aligned with land-based production. However, rural credit markets in China have long been trapped in a "double bind" of insufficient formal credit supply and high-risk informal lending.
Methods: Using four waves (2016–2022) of China Family Panel Studies data on landholding households, we examine whether and how digital payment promotes the formalization of rural household finance.
Results: The results show that digital payment significantly shifts borrowing from informal sources toward banks and other formal institutions. This effect operates mainly through two channels—strengthening demand for formal borrowing and improving access to formal financial products. In doing so, digital payment provides more stable funding for land-related investments such as land transfers and farmland infrastructure. The effect is stronger among financially vulnerable households, underscoring its inclusive nature.
Discussion: The findings show how digital finance can bridge sustainability and development in dynamic land-use and rural socioeconomic–environmental interactions, and offer policy implications for leveraging digital payment to improve rural financial ecosystems and better coordinate land and financial capital.

KEYWORDS

China, digital payment, finance formalization, financial vulnerability, landholding households, rural household finance

1 Introduction

Developing modern agriculture and improving the allocative efficiency of arable land are central to safeguarding national food security and advancing rural revitalization. As a sector that relies primarily on land as its main production factor, agriculture plays an irreplaceable foundational role in stabilizing grain supply, protecting ecosystems, and supporting farm household income growth. Rural credit markets, which connect financial resources with land-intensive rural economic activities, are therefore a key mechanism for optimizing land allocation and promoting sustainable agricultural development (World Bank, 2008; Zeller and Sharma, 1998). With the rapid advance of modern agriculture, farm production has been shifting from fragmented, small-scale cultivation toward larger-scale and more intensive operations, which in turn requires continuous, efficient, and well-targeted financial support (Khan et al., 2024; Dong et al., 2012).

Recognizing the critical importance of rural finance for modern agriculture and rural revitalization, the Chinese central government has introduced a series of policy initiatives to

strengthen the rural financial system. In 2013, the former China Banking Regulatory Commission issued the *Measures for the Administration of Farmer Loans*, expanding bank credit to agriculture and increasing the supply of loans to farm households, thereby laying the foundation for their access to formal finance. In 2023, the State Council released the *Implementation Opinions on Promoting the High-quality Development of Inclusive Finance*, which set the goal of establishing a high-quality inclusive financial system within 5 years and provided overall guidance for rural finance legislation. The 2025 No. 1 Central Document further focuses on rural revitalization and explicitly calls on financial institutions to increase credit support for sectors related to rural revitalization.

Despite strong policy attention from the central government, China's rural credit markets remain caught in a "double bind" and fail to meet farm households' financial needs under modern agricultural development. On the one hand, although formal credit is regulated and relatively low risk, weak rural credit information systems, insufficient collateral, and limited branch networks prevent formal institutions from effectively serving households' small, short-term liquidity needs as well as their larger, long-term investment needs for scaled-up operations (Stiglitz and Weiss, 1981; Dong et al., 2012). On the other hand, informal finance, while flexible and able to fill service gaps, is often characterized by weak regulation, high interest rates, and opaque information, which can lead to debt spirals and abusive collection practices and thereby undermine the health of the rural financial ecosystem (Turvey et al., 2010; Lin et al., 2019). As agricultural production shifts toward larger-scale, more intensive, and more technology-intensive systems, farm households are moving toward "high-investment, long-cycle, high-return" market-oriented operations, which further increases their demand for stable and sustained financial support (World Bank, 2008; Khan et al., 2024; Dong et al., 2012). Against this backdrop, resolving the rural finance double bind is not only a practical challenge for normalizing rural credit markets but also a necessary condition for enabling smallholders to transition into larger commercial operations and to be integrated into modern agricultural systems.

The rapid expansion of digital payment offers a new avenue on both the supply and demand sides for shifting farm households toward formal finance. It is useful to distinguish digital payment from the broader concept of digital finance: digital finance typically encompasses a wider range of digitally enabled financial services (e.g., digital credit, insurance, and wealth management), whereas digital payment primarily refers to transaction and settlement technologies that generate high-frequency and verifiable transaction records. On the supply side, digital payment helps overcome the "last-mile" problem of formal financial service delivery: by relaxing geographic constraints associated with physical branches, it allows banks and other formal institutions to extend services into remote rural areas, filling gaps previously occupied by informal lenders and reducing households' reliance on informal credit (Ozili, 2018; Liu et al., 2024a, b). The transparency of digital payment also facilitates real-time tracking of fund flows, which standardizes loan use and lowers ex post monitoring costs for formal institutions (Liu et al., 2024a, b).

On the demand side, frequent use of digital payment reshapes the behavioral foundations of household financial decisions. Regular users of digital payment tend to accumulate higher levels of financial literacy and digital skills and to develop greater trust in formal financial services (Wang and Wang, 2022; Chen et al., 2024). By allowing households to learn about and access formal financial products directly via mobile phones and other devices, digital payment reduces information and transaction barriers to using formal finance (Li et al., 2020). At the same time, the broader digitalization process may also stimulate credit demand and raise indebtedness risks, suggesting that the net welfare implications can be context-dependent and need to be understood through the lens of households' financing-channel choices. In the context of the new wave of technological change, Chinese smallholders, while still embedded in traditional land-based production, are seeing their financing behavior progressively reshaped by digitalization. These developments raise two related questions: does the use of digital payment promote the formalization of rural household finance, and, if so, through what mechanisms does it shape households' choice of financing channels? Addressing these questions helps clarify how smallholder financing behavior is evolving in the digital era and provides policy insights on using digital payment as a lever to break the rural finance double bind.

As information technologies and formal financial services increasingly penetrate agricultural production and rural life, a growing body of work has examined the role of digital payment and digital finance in rural financial development. However, the existing evidence is not fully uniform: while many studies emphasize improvements in financial inclusion and market efficiency, others point to rising indebtedness and heterogeneous (and sometimes opposing) impacts across households and local financial environments. The literature most relevant to this study can be grouped into three strands. The first examines how digital technologies reshape rural households' production and consumption patterns. Using microdata such as the China Household Finance Survey, existing studies show that digital finance and mobile payment significantly increase consumption by farm and rural households, with heterogeneous effects across expenditure and income groups (Li et al., 2020; Dai and Wang, 2022). Subsequent work finds that digital finance can relax liquidity constraints and improve access to consumption opportunities, thereby reducing consumption inequality across households (Chen et al., 2024; Wang et al., 2025). Yet these consumption-expanding effects can also be accompanied by increased borrowing and repayment pressure, implying a potential tension between short-run welfare gains and longer-run debt sustainability. Other studies focus on agricultural production resilience and show that digital finance can expand financing scale, improve access to information, and raise participation in agricultural insurance, all of which substantially strengthen the resilience of farm production systems that depend heavily on land.

The second strand analyzes the evolution and constraints of the formalization of farm household financing channels. This literature documents that endowments and off-farm employment significantly affect households' choice between formal and informal finance. On the one hand, off-farm work and higher, more stable income promote a shift toward formal financing (Ayyagari et al., 2010; Lin et al., 2019). On the other hand, in paddy and other intensive farming areas, close cooperative relationships and strong local trust often reinforce reliance on informal channels such as borrowing from relatives and friends (Turvey et al., 2010; Turvey and Kong, 2010). Micro-level evidence from rural China further shows that personal reputation and social networks—forms of social capital—facilitate access to bank credit, whereas kinship-based ties tend to push households toward informal finance (Turvey and Kong, 2010; Lin et al., 2019). The third strand studies the broader impact of digital technologies on rural financial systems. Existing research finds that the adoption of digital finance

and digital payment can substantially improve financial access and inclusion for rural households (Wen et al., 2024; Ozili, 2018), but may also stimulate additional credit demand while boosting consumption, thereby increasing overall household indebtedness and the risk of over-indebtedness (Chai and Qi, 2025; Meyll and Walter, 2019).

While this literature provides an important foundation for understanding digital payment and rural household financing behavior, two gaps remain with respect to the formalization of financing channels. First, in terms of research focus, most existing studies examine the effects of digital technologies on credit access or loan volumes in general, whereas relatively few explicitly focus on the critical transformation from informal to formal financing—namely, the formalization of financing channels. The potential "bridge" role of digital payment, which is the most widely used digital technology in rural areas, in guiding this transformation has not received sufficient attention. Second, with regard to mechanisms, it remains largely unexplored whether and how digital payment promotes the shift toward formal channels by reshaping households' borrowing preferences and improving their access to formal financial products. Building on these gaps, this study uses four waves (2016–2022) of CFPS household-level data and a sample of farm households defined by contracted and operational land rights to examine, from a landholding perspective, the impact of digital payment on the formalization of rural household finance and the mechanisms through which it operates.

Our empirical analysis yields three key findings. First, the use of digital payment significantly promotes the formalization of rural household finance by increasing households' reliance on banks and other formal institutions rather than informal channels, and this relationship remains highly robust across alternative specifications, propensity score matching, and instrumental variable estimation. Second, digital payment operates through both demand- and supply-side mechanisms: it strengthens households' preference for formal borrowing and improves their access to formal financial products. Third, the effect exhibits marked heterogeneity. Digital payment has a stronger impact among male-headed households, households in the eastern region, and low-income households, while the effect is weaker or statistically insignificant for female-headed households and those in central and western regions. These results underscore the inclusive-finance potential of digital payment in reshaping financing structures among landholding households.

The remainder of this paper is organized as follows. Section 2 develops the theoretical framework and research hypotheses. Section 3 introduces the data, variables, and empirical strategy. Section 4 presents the empirical results, including baseline estimates, robustness checks, mechanism analysis, and the heterogeneity analysis. Section 5 concludes with a discussion of the main findings and offers targeted policy implications for leveraging digital payment to improve the formalization of rural household finance.

2 Theoretical framework and research hypotheses

2.1 Digital payment and finance formalization

In traditional rural credit markets, a core tension arises from "double" information asymmetry between formal financial institutions and farm households, which in turn generates high transaction costs and constitutes a fundamental obstacle to the formalization of household finance. On the supply side, many farm households lack collateral or formal credit histories, making it difficult for banks to accurately assess their repayment capacity and creditworthiness. As a result, households often face severe financial exclusion and credit rationing (Conning and Udry, 2007; Dong et al., 2010; Lin et al., 2019). On the demand side, sparse branch networks, long physical distances, and limited understanding of complex loan approval procedures and electronic contract terms create a sense of distance and mistrust toward formal finance among rural households (Beck et al., 2007; Cole et al., 2011). This structural divide on both the supply and demand sides leads households to rely heavily on informal channels—such as borrowing from relatives and friends or using high-interest informal loans—which raises their financing costs and seriously constrains both the modernization of the rural financial system and the scaling up of land-based agricultural production (Turvey and Kong, 2010; Lin et al., 2019).

The diffusion of digital payment provides a potential way to ease this constraint. Digital payment can effectively mitigate double-sided information asymmetry and reduce transaction costs. By digitizing households' economic activities—including purchases of agricultural inputs, sales of farm products, and daily consumption—digital payment generates continuous, dynamic, and traceable "digital footprints" that form the basis of households' "digital credit" (Berg et al., 2020; Björkegren and Grissen, 2020). This transformation mechanism has the potential to convert previously unobservable, implicit creditworthiness into assessable and bankable credit information, thereby relaxing the traditional collateral-based barrier to accessing formal loans (Björkegren and Grissen, 2020; Berg et al., 2020). At the same time, frequent use of digital payment is also a process through which households accumulate financial literacy and digital trust: as they become familiar with user interfaces and learn about electronic contracts, account management, and related financial concepts, their financial literacy gradually improves (Berg et al., 2020; Cole et al., 2011). Recent micro-level evidence from rural China confirms this channel. Using household survey data, Ding et al. (2025) show that rural residents' adoption of digital payment significantly improves their credit availability, underscoring the role of payment data in easing information frictions and expanding access to formal financial services. Through repeated and secure interactions with the digital interfaces of formal institutions, households develop a sense of familiarity and trust, which strengthens their preference for formal finance over informal alternatives (Shao et al., 2019).

More specifically, digital payment can help resolve the rural finance double bind and promote the formalization of household finance through two core channels: strengthening demand for formal borrowing and improving the accessibility of formal financial services. On the demand side, widespread use of digital payment can stimulate borrowing needs that are oriented toward formal channels, thereby encouraging a shift in households' financing structure. First, the convenience of digital payment and the broader business horizons it enables accelerate the marketization and scaling up of farm household production, generating new and larger demand for productive investment (Zhang, 2022; Zhao et al., 2022). By making it easier for farm households to connect with e-commerce platforms, large buyers, and broader markets, digital payment supports a transition in production modes—from fragmented plots to more consolidated land

bases and from backyard livestock production to larger-scale operations (Zhang, 2022). The capital needed to purchase machinery, build storage facilities, and hire labor for such expansion far exceeds the typical "small, short-term" loans available from informal sources, effectively pushing households to seek agricultural business loans and policy-based credit from formal institutions instead (Yan et al., 2025). Along similar lines, Chen and Xiao (2025) find that digital payment adoption substantially enhances Chinese farmers' access to formal credit by alleviating both conditional and price exclusion in rural credit markets, while simultaneously strengthening informal credit networks. Second, the process of using digital payment also familiarizes households with financial concepts and products. As farmers deepen their understanding of interest rates, loan terms, and credit, their fear of and aversion to formal financial products decline, and their willingness and capacity to bear risk may increase (Li et al., 2020). This shift raises their demand for formal borrowing, rather than leaving formal finance as a last resort used only under severe distress when informal lending is no longer available.

On the supply side, digital payment can enhance the accessibility of financial services and thereby foster the formalization of household finance. By relaxing geographic constraints, digital payment greatly reduces transaction costs (Zhang, 2022; Kong and Loubere, 2021). Delivered via mobile devices, it helps overcome the "last mile" problem created by sparse branch networks in sparsely populated rural areas. Farmers can more easily complete the entire process from obtaining product information and submitting loan applications to receiving funds, which substantially increases access to formal financial services. In addition, the data generated by digital payment enable financial institutions to adopt big-data-based risk management. This allows lenders to move beyond traditional collateral- and balance-sheet-based lending technologies, build credit files for large numbers of previously "unscored" rural clients, and design credit products that better match their risk profiles (Berg et al., 2020; Yu et al., 2022). In essence, digital payment provides a technological means of bringing farm households into the orbit of formal finance and has the potential to generate a step change in financial inclusion.

Based on the above analysis, we argue that digital payment can promote the formalization of rural household finance by activating demand for formal borrowing and improving the accessibility of formal financial services. Accordingly, we propose the following hypotheses:

> *H1*: Digital payment use promotes the formalization of rural household finance.
>
> *H2*: Digital payment promotes the formalization of rural household finance by strengthening households' demand for formal borrowing.
>
> *H3*: Digital payment promotes the formalization of rural household finance by improving households' access to formal financial services.

2.2 Financial vulnerability as a moderator

The analysis above suggests that digital payment promotes the formalization of rural household finance through two core channels—strengthening demand for formal borrowing and improving access to formal financial services. However, the strength of this effect is likely to vary with households' micro-level economic characteristics. In particular, household financial vulnerability, which captures the robustness of a household's financial position and its ability to cope with shocks, is expected to moderate the enabling effect of digital payment. Financial vulnerability refers to the likelihood that a household will fall into financial distress when exposed to internal or external shocks, and is typically manifested in volatile income, limited savings, and heavy debt burdens (Lusardi et al., 2011; Liu Z. et al., 2024; Liu J. et al., 2024).

On the demand side, financial vulnerability amplifies the marginal benefit of using digital payment to alleviate financing constraints. For households in relatively strong financial positions, financing channels are already more diversified, and digital payment mainly offers a more convenient way to access existing options (Ayyagari et al., 2010; Beck et al., 2007). By contrast, financially vulnerable households often lack collateral and stable income documentation and are thus excluded from formal credit for long periods; they become prime clients of high-cost informal lenders (Stiglitz and Weiss, 1981; Turvey and Kong, 2010). When these households face acute liquidity constraints, being able to build "digital credit" through digital payment and thereby qualify for formal loans yields substantial marginal gains and strong incentives. This, in turn, motivates them to actively use digital payment tools and seek formal finance as a substitute for costly informal channels (Jack and Suri, 2014; Suri and Jack, 2016). Using both macro and household-level data for China, Shen (2025) shows that digital financial inclusion tends to generate a "digital dividend" for disadvantaged groups: low-income and rural households experience larger income gains than richer or urban households. We therefore expect that, especially for financially vulnerable landholding households, digital payment exerts a stronger pull toward formal financing channels. Based on this reasoning, we propose the following hypothesis:

> *H4*: Household financial vulnerability positively moderates the effect of digital payment on the formalization of rural household finance; that is, the positive impact of digital payment on finance formalization is stronger for more financially vulnerable households.

3 Research design

3.1 Data source

This study uses data from the China Family Panel Studies (CFPS), a nationally representative longitudinal survey that covers households and all their members in 25 provinces, municipalities, and autonomous regions in China and provides rich information on social, economic, and demographic characteristics (Xie and Hu, 2014). CFPS has been conducted regularly since 2010, with follow-up interviews carried out annually or biennially. The survey is implemented jointly by the Institute of Social Science Survey at Peking University and the Survey Research Center at the University of Michigan. The China Family Panel Studies (CFPS) are approved by the Peking University Biomedical Ethics Review Committee (approval number IRB00001052-14010).

For the purposes of this paper, we draw on four survey waves from 2016 to 2022 and conduct the following sample refinements. Specifically, we construct the analytical sample in three sequential steps. First, given ongoing reforms of the household registration (hukou) system and the gradual rollout of unified urban–rural household registration, using hukou status to identify farm households may be inaccurate, and the timing of reform differs across regions. We therefore follow the literature on China's rural land rights and the "separation of three rights" (Liu et al., 1998; Li et al., 2020) and define farm households based on farmland rights. Specifically, households that hold contracted land-use rights and/or operational rights to farmland are classified as landholding farm households. In practice, we identify such households according to whether they have been allocated collective land and whether they rent in land from others. In other words, we retain households that report at least one of the following: (i) being allocated collective farmland (proxying contracted land-use rights), or (ii) renting in farmland from others (proxying operational rights). Second, because our focus is on the formalization of external financing channels, households without any borrowing are excluded from the analysis. Finally, observations with missing values on key variables are dropped. After these steps, we obtain an unbalanced panel of 3,494 household-year observations from 2016 to 2022. This step-by-step description clarifies how the final landholding-and-borrowing sample is obtained from the CFPS waves used in the analysis.

3.2 Variable definitions and descriptive statistics

3.2.1 Dependent variable

Formalization of rural household finance. The dependent variable captures the degree to which a household's external financing relies on formal financial institutions through its primary (dominant) borrowing channel. Following prior work that distinguishes between formal and informal financing channels (Ayyagari et al., 2010; Turvey and Kong, 2010), we classify households' main borrowing channels into three ordered categories: a value of 1 is assigned if the household borrows only from informal channels (such as relatives, friends, or private lenders), 2 if it borrows from both informal channels and formal institutions, and 3 if it borrows only from formal financial institutions. This ordered variable thus increases with the extent to which a household relies on formal finance via its main borrowing source and reflects a higher level of finance formalization in the household's primary borrowing channel, rather than a complete characterization of its borrowing portfolio.

3.2.2 Key independent variable

Digital payment. In line with studies that use online financial behavior or internet use as proxies for digital finance or digital payment (Li et al., 2020), we use whether the household engages in online shopping as a proxy for digital payment use. In rural settings, online shopping typically requires linking a mobile payment account and completing repeated electronic transactions; it therefore captures households' active engagement with digital payment tools and the broader digital payment ecosystem, rather than purely incidental exposure. This measure captures the diffusion of digital payment tools among landholding households and allows us to examine their potential impact on the formalization of household finance. We acknowledge that some households may frequently use digital payment for in-person QR-code payments or transfers without engaging in online shopping; thus, our measure should be interpreted as a proxy for deeper/embedded digital payment engagement rather than a comprehensive measure of all digital payment usage.

3.2.3 Mediating variables

To measure households' preference for formal rather than informal borrowing, we draw on existing research that uses the choice of loan counterparties to proxy attitudes toward formal finance (Allen et al., 2016; Beck et al., 2007). CFPS asks: "If your household needed to borrow a relatively large sum of money (for example, to buy a house or for business turnover), whom would you turn to first?" We code this variable as 1 if the respondent's first choice is a bank or other formal financial institution and 0 if the first choice is parents or children, relatives, friends, or other informal channels. This indicator reflects the extent to which households prefer formal financing sources when making borrowing decisions.

Following Allen et al. (2016), we construct an indicator of financial product access based on the CFPS question "Do you hold any financial products?" The variable equals 1 if the household reports holding any financial products and 0 otherwise. This measure captures whether households can access and hold formal financial products and thus serves as a proxy for the accessibility of formal financial services.

3.2.4 Control variables

Guided by the literature on determinants of the formalization of household financing channels (Ayyagari et al., 2010; Beck et al., 2007; Turvey and Kong, 2010), we control for a set of characteristics of the household financial decision-maker (e.g., demographic and human capital attributes), household characteristics (e.g., income and composition), and province fixed effects. These controls help mitigate omitted-variable bias and allow us to more accurately identify the relationship between digital payment and the formalization of rural household finance among landholding households. Descriptive statistics for all variables are reported in Table 1.

3.3 Model specification

3.3.1 Baseline regression

The dependent variable in this study is the degree of finance formalization, which is an ordered variable. We therefore estimate a panel ordered probit model. Fixed-effects estimation of panel ordered probit models typically suffers from the incidental parameters problem, which can lead to inconsistent coefficient estimates (Greene, 2012; Wooldridge, 2010). In addition, the LR test for the random-effects specification in Table 2 rejects the pooled ordered probit model. We therefore adopt a random-effects panel ordered probit model as our baseline specification. Following the standard setup for ordered choice models and limited dependent variables in panel data (Greene,

TABLE 1 Variable definitions and descriptive statistics.

Variable	Variable definition and coding	Mean	Std. dev.	Min	Max
Finance formalization	1 = informal only; 2 = both informal and formal; 3 = formal only	2.928	0.296	1	3
Digital payment	Online shopping = 1	0.212	0.409	0	1
Formal borrowing preference	First borrowing choice is bank/other formal institution = 1	0.301	0.459	0	1
Access to financial products	Holds any formal financial product = 1	0.019	0.136	0	1
Household financial vulnerability	Monthly income < monthly expenditure = 1	0.309	0.462	0	1
Gender	1 = male	0.594	0.491	0	1
Age	Age of decision-maker	49.554	11.665	17	90
Hukou type	1 = agricultural hukou	0.941	0.236	0	1
Health status	Self-rated health, 1–5 = very poor–very good	3.139	1.232	1	5
Marital status	1 unmarried; 2 married; 3 cohabiting; 4 divorced; 5 widowed	2.089	0.574	1	5
Years of education	Years of schooling	6.446	4.382	0	16
Household size	Number of household members	4.317	1.905	1	14
Wage income	Log of annual wage income	10.328	0.716	5.298	13.122
Net income	Log of annual net income	10.843	1.002	5.075	14.712
Major shock	Major adverse event in past year = 1	0.165	0.371	0	1

2012; Wooldridge, 2010), we specify the following latent-variable model:

$$Y_{it}^{*} = \alpha_0 + \alpha_1 SZ_{it} + \sum \alpha_{it} control_{it} + \varepsilon_{it} \quad (1)$$

where Y_{it}^{*} is an unobserved latent variable; SZ_{it} denotes the digital payment variable; $control_{it}$ is a vector of control variables, including characteristics of the household financial decision-maker, household characteristics, and province dummies; α_0, α_1, and α_{it} are parameters to be estimated; and ε_{it} is a random error term assumed to follow a standard normal distribution. The observed ordered outcome Y_{it}, which measures the degree of finance formalization for household i in period t, is linked to the latent variable Y_{it}^{*} through a set of thresholds $\{\tau_j\}$ as shown in Equation (2):

$$Y_{it} = j \Leftrightarrow \tau_{j-1} < Y_{it}^{*} \leq \tau_j \quad (2)$$

where j indexes the ordered categories and τ_j are the cut points to be estimated. Based on this structure, we employ a random-effects ordered probit model for the empirical analysis.

3.3.2 Mechanism analysis

The preceding discussion suggests that formal borrowing preference and access to financial products are key channels through which digital payment may promote the formalization of rural household finance. Among the available approaches to testing mediation, the traditional "three-step" procedure has been shown to yield biased estimates in the third step and to perform poorly in assessing the statistical significance of indirect effects (MacKinnon et al., 2007; Imai et al., 2010). We therefore focus on estimating the effect of the core explanatory variable—digital payment—on the two mediators, while the role of these mediators in shaping finance formalization has already been articulated in the theoretical framework. The mechanism test is implemented using the specification in Equation (3).

$$M_{it} = \alpha_0 + \alpha_1 SZ_{it} + \alpha_2 Control_{it} + \varepsilon_{it} \quad (3)$$

where M_{it} denotes the mediator (either formal borrowing preference or access to financial products); SZ_{it} is the digital payment variable; $Controls_{it}$ is a vector of control variables, including characteristics of the household financial decision-maker, household characteristics, and province dummies; α_0, α_1, and α_2 are parameters to be estimated; and ε_{it} is a random error term assumed to follow a standard normal distribution. A statistically significant α_1 indicates that digital payment has a meaningful effect on the mediator, consistent with the proposed mechanism.

We further examine whether household financial vulnerability moderates the impact of digital payment on finance formalization. To this end, we augment the baseline model in Equation 1 by including both the financial vulnerability variable and its interaction with digital payment. A statistically significant interaction term implies that household financial vulnerability exerts a moderating effect; otherwise, no moderating effect is present. The moderating specification is given by:

$$Y_{it}^{*} = \alpha_0 + \alpha_1 SZ_{it} + \alpha_2 FC_{it} + \alpha_3 \left(SZ_{it} \times FC_{it} \right) + \sum \alpha_{it} control_{it} + \varepsilon_{it} \quad (4)$$

where Y_{it}^{*} is the latent variable underlying the observed ordered measure of finance formalization; SZ_{it} is the digital payment variable; FC_{it} denotes household financial vulnerability; $SZ_{it} \times FC_{it}$ is their interaction term; $control_{it}$ is the vector of control variables described above; α_0, α_1, α_2, α_3, and α_{it} are parameters to be estimated; and ε_{it} is a standard normally distributed error term.

10.3389/fsufs.2025.1759687

4 Empirical results and analysis

4.1 Baseline regression results

We begin by examining the baseline association of digital payment on the formalization of rural household finance. Because the dependent variable is an ordered categorical variable, we estimate an ordered probit model. Table 2 reports the baseline results based on Equation 1. Column (1) shows a statistically significant positive association between digital payment and the degree of finance formalization. Because ordered probit coefficients are estimated on a latent index and are not directly interpretable in probability units, we focus on marginal effects for substantive interpretation. Columns (2)–(4) present the marginal effects of digital payment and the corresponding test statistics. The estimates indicate that the use of digital payment reduces the probability that a household borrows only from informal channels by 0.5 percentage points and the probability of using both informal and formal channels by 1.7 percentage points, while increasing the probability of relying only on formal channels by 2.2 percentage points. Although these average probability changes are modest in absolute terms, they translate into meaningful shifts at scale: per 1,000 landholding households, digital payment use is associated with about 22 additional households relying exclusively on formal borrowing (holding other covariates constant). These results suggest that digital payment is associated with households' reliance on informal financing and raises their likelihood of borrowing exclusively from formal institutions, implying a gradual shift in borrowing patterns toward more formalized financing structures. Thus, hypothesis H1 is supported.

Table 3 reports the odds ratios from an ordered logit specification, which can be interpreted as the ratio of the odds of being in a higher versus a lower level of finance formalization for users of digital payment relative to nonusers. The odds ratio for digital payment is 1.346, clearly above the benchmark value of one and the largest among all covariates. This implies that, holding other factors constant, the odds of being at a higher level of finance formalization are about 35% greater for households that use digital payment than for those that do not. In contrast, the odds ratios for most control variables are closer to one in absolute value, indicating more modest associations with finance formalization. Taken together, these results further confirm the strong and economically meaningful positive association between digital payment and the formalization of rural household finance.

TABLE 2 Effects of digital payment on finance formalization.

Variable	Oprobit	1	2	3
	(1)	(2) dy/dx	(3) dy/dx	(4) dy/dx
Digital payment	0.297*	−0.005*	−0.017**	0.022**
	(0.153)	(0.003)	(0.008)	(0.011)
Gender	−0.266**	0.005**	0.015**	−0.020**
	(0.123)	(0.002)	(0.007)	(0.009)
Age	0.027***	−0.000***	−0.001***	0.002***
	(0.006)	(0.000)	(0.000)	(0.000)
Hukou type	−0.119	0.002	0.007	−0.008
	(0.258)	(0.005)	(0.015)	(0.019)
Health status	−0.053	0.001	0.003***	−0.004
	(0.046)	(0.001)	(0.003)	(0.003)
Years of education	0.042***	−0.001***	−0.002	0.003***
	(0.015)	(0.000)	(0.001)	(0.001)
Marital status	0.012	−0.000	−0.001	0.001
	(0.105)	(0.002)	(0.006)	(0.008)
Household size	−0.019	0.000	0.001	−0.001
	(0.031)	(0.001)	(0.002)	(0.002)
Household wage income	0.023	−0.000	−0.001	0.002
	(0.078)	(0.001)	(0.004)	(0.006)
Household net income	−0.129**	0.002**	0.007**	−0.010**
	(0.063)	(0.001)	(0.004)	(0.005)
Major household shock	0.019	−0.000	−0.001	0.001
	(0.136)	(0.002)	(0.008)	(0.010)
Province fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Wald test	36.68***	–	–	–
Log likelihood	−844.23922	–	–	–
LR test	55.14***	–	–	–
Observations	3,494	3,494	3,494	3,494

Robust standard errors are reported in parentheses. ***, **, and * indicate significance at the 1, 5, and 10% levels, respectively. Columns (2)–(4) report the marginal effects of digital payment.

TABLE 3 Odds ratios of explanatory variables from the ologit model.

Variable	Odds ratio (OR)
Digital payment	1.346
Gender	0.667
Age	1.034
Hukou type	0.834
Health status	0.935
Years of education	1.063
Marital status	1.013
Household size	0.981
Household wage income	0.945
Household net income	0.768
Major household shock	0.993

4.2 Addressing endogeneity

Drawing on the existing literature, our ordered response model may face three main sources of endogeneity. First, sample selection bias may arise because the dependent variable is defined only for households that have engaged in borrowing, so households without borrowing are excluded and their potential degree of finance formalization is unobserved. Second, there may be reverse causality: while the diffusion of digital payment can reduce transaction costs, improve access to financial services, and encourage a shift toward formal channels, households that already prefer formal borrowing may also be more likely to adopt and intensively use digital payment tools to meet eligibility requirements and build credit histories. Third, omitted-variable bias may persist even after controlling for a rich set

of individual and household characteristics as well as province and year fixed effects, since some unobserved factors affecting finance formalization may remain. Given that CFPS is a high-quality survey implemented under strict protocols, we abstract from measurement-error-driven endogeneity and focus on these three concerns. To examine the robustness of our baseline association, we employ propensity score matching (PSM) to mitigate selection bias and use an instrumental-variables (IV) strategy to deal with reverse causality and omitted variables.

4.2.1 Propensity score matching (PSM)

Given the potential for selection bias, we first apply PSM to construct a more comparable treatment–control sample. Specifically, we define the treatment group as households that use digital payment and the control group as those that do not. We then match treated and control households with similar observable characteristics to re-estimate the causal effect of digital payment on finance formalization. To align with our research objective, we adopt three commonly used matching algorithms—nearest-neighbor matching, radius matching, and caliper matching—to implement the PSM procedure. The detailed matching diagnostics are reported in Table 4.

After matching, most control variables exhibit standardized biases below 10 percent, and for most variables the reduction in bias exceeds 80 percent. In addition, mean differences in control variables between the treatment and control groups are statistically insignificant, and *t*-tests fail to reject the null of no systematic differences, indicating that the matched samples achieve good covariate balance. Across all three matching methods, the estimated treatment effects are highly consistent with the baseline regression results. As reported in Table 5, even after addressing selection bias, digital payment continues to exert a statistically significant positive effect on the formalization of rural household finance.

4.2.2 Instrumental variables (IV) approach

We next address potential endogeneity using an instrumental variables strategy, taking "mobile internet access" as an instrument for digital payment. Because the dependent variable—the degree of finance formalization—is an ordered categorical variable, conventional linear IV models cannot be applied directly. Following Roodman's (2011) conditional mixed process (CMP) framework, we therefore combine IV estimation with CMP and estimate a recursive system akin to an IV probit using the *cmp* command (hereafter referred to as the IV–CMP model) to deal with possible reverse causality and omitted-variable bias.

To assess the validity of mobile internet access as an instrument, we also estimate a linear two-stage least squares (2SLS) model, following Chyi and Mao (2012). The first-stage regression yields an F-statistic of 577.910, which is far above the conventional threshold of 10 and statistically significant at the 1% level, indicating a strong correlation between mobile internet access and digital payment. This provides empirical evidence against the weak-instrument concern. The result remains robust even when allowing for heteroskedasticity, suggesting that mobile internet access is a strong and relevant instrument. The identification relies on the maintained exclusion restriction that, conditional on the rich set of household controls and province and year fixed effects, mobile internet access affects finance formalization primarily through its impact on digital payment.

Table 6 reports the IV–CMP estimation results. In the first-stage equation, the coefficient on mobile internet access is positive and statistically significant at the 1% level, confirming its relevance as an instrument and supporting the plausibility of our identification strategy. In the second-stage equation, the coefficient on digital payment remains positive and statistically significant at the 5% level. This indicates that, even after accounting for potential reverse causality and omitted variables, digital payment continues to exert a positive effect on the formalization of rural household finance, further reinforcing our main findings.

4.3 Robustness checks

We further assess the robustness of the baseline results by examining odds ratios, marginal effects, and by addressing endogeneity using PSM and IV. In all cases, the main conclusion remains unchanged. Building on this, we conduct three additional checks on model specification and estimation to further enhance the reliability and comprehensiveness of our findings.

4.3.1 Mundlak approach

To test for correlation between individual effects and the explanatory variables, we follow Mundlak's (1978) "correlated random effects" approach by augmenting the random-effects specification with household-level means of the time-varying regressors. This within–between formulation allows the individual effects to be correlated with the explanatory variables, while retaining the efficiency advantages of a random-effects estimator. The results, reported in Table 7, show that the joint test of the mean variables is not statistically significant ($\chi^2 = 5.727$, $p = 0.678$), indicating no evidence of systematic correlation between the unobserved individual effects and the regressors. This supports the use of the random-effects specification adopted earlier and suggests that our baseline random-effects ordered probit model is appropriate, alleviating concerns that unobserved individual heterogeneity drives the main results.

4.3.2 Pooled ordered probit with clustered standard errors

To account for the ordered nature of the dependent variable (finance formalization) and possible within-household correlation, we re-estimate a pooled ordered probit model and compute cluster-robust standard errors at the household level. The results in Table 8 show that the coefficient on digital payment is 0.207 and statistically significant at the 5% level (standard error = 0.094). The marginal effects (dy/dx) are also statistically significant across outcome categories. The Wald statistic is 35.85 ($p < 0.01$), and the log-likelihood is −877.15823, indicating a good overall fit. These findings are consistent with the baseline estimates and again confirm the positive impact of digital payment on the formalization of rural household finance.

4.3.3 Alternative definition of the dependent variable

As a further robustness check, we redefine the dependent variable as a binary indicator of finance formalization. Specifically, we assign a value of 0 if the household borrows only from informal channels (relatives and friends), and a value of 1 if it borrows from banks only or from both banks and informal channels. Under different

TABLE 4 Covariate balance tests and matching treatment effects.

Control variable	Matching status	Mean (M)		Standardized bias (%)	Bias reduction (%)	Difference between groups	
		TG	CG			t	P > |t|
Gender	U	0.602	0.590	2.3	−107.0	0.550	0.583
	M	0.602	0.625	−4.7		−0.910	0.361
Age	U	40.39	52.023	−108.9	98.5	−26.360	0.000
	M	40.39	40.565	−1.6		−0.320	0.751
Hukou type	U	0.891	0.954	−23.4	87.9	−6.380	0.000
	M	0.891	0.899	−2.8		−0.470	0.637
Health status	U	2.891	3.2063	−26.3	97.4	−6.200	0.000
	M	2.891	2.884	0.7		0.130	0.893
Years of education	U	9.403	5.654	94.8	92.3	22.040	0.000
	M	9.403	9.113	7.3		1.580	0.114
Marital status	U	2.026	2.106	−14.1	82.5	−3.370	0.001
	M	2.026	2.012	2.5		0.490	0.621
Household size	U	4.413	4.291	6.4	−16.6	1.540	0.124
	M	4.413	4.554	−7.4		−1.460	0.146
Household wage income	U	10.487	10.285	26.0	84.6	6.830	0.000
	M	10.487	10.456	4.0		0.690	0.489
Household net income	U	11.341	10.709	66.7	93.9	15.770	0.000
	M	11.341	11.303	4.0		0.830	0.045
Major household shock	U	0.169	0.163	1.6	−94.1	0.390	0.694
	M	0.169	0.157	3.2		0.610	0.542
Middle	U	0.342	0.377	−7.3	73.7	−1.750	0.080
	M	0.342	0.352	−1.9		−0.370	0.710
weat	U	0.054	0.061	−3.1	11.8	−0.740	0.460
	M	0.054	0.061	−2.7		−0.530	0.597
Year2018	U	0.294	0.270	5.2	43.1	1.260	0.206
	M	0.294	0.280	3.0		0.560	0.572
Year2020	U	0.225	0.171	13.5	35.6	3.350	0.001
	M	0.225	0.259	−8.7		−1.550	0.122
Year2022	U	0.304	0.136	41.5	94.9	10.980	0.000
	M	0.304	0.313	−2.1		−0.360	0.722

***, **, and * indicate significance at the 1, 5, and 10% levels, respectively.

assumptions about individual effects, we then estimate pooled, random-effects (RE), and fixed-effects (FE) panel logit models. Table 9 reports the results, with all coefficients presented as average marginal effects (dy/dx) for ease of interpretation.

Column (1), which reports the pooled logit results, indicates that digital payment increases the probability of finance formalization by 0.9 percentage points. Column (2) presents the random-effects estimates. The LR test rejects the null hypothesis that the panel-level variance component is zero, implying that the pooled model is not appropriate and that the RE specification should be preferred; under RE, the estimated marginal effect of digital payment is again 0.9 percentage points. Column (3) shows the fixed-effects logit results, based on only 139 observations. The sharp reduction in sample size arises because FE logit requires at least two observations per household with variation in the dependent variable, leading to the exclusion of all households with no within-household change. This substantially reduces estimation efficiency. Since FE identification relies solely on within-household variation, limited within-household changes in the key regressor (digital payment) may result in insufficient identifying variation, which likely explains the statistically insignificant marginal effect of digital payment in the FE model. The Hausman test fails to reject the null hypothesis that individual effects are uncorrelated with the regressors, supporting the random-effects specification as the most appropriate. These robustness checks further strengthen our confidence in the baseline conclusion that digital payment promotes the formalization of rural household finance.

TABLE 5 PSM estimates: digital payment and rural household finance formalization.

Variable	Nearest-neighbor matching (1:1)	Radius matching	Caliper matching
ATT	0.037** (0.017)	0.035* (0.020)	0.031** (0.013)
Covariates	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Province fixed effects	Yes	Yes	Yes
Observations	3,494	3,494	3,494

Reported coefficients are average treatment effects on the treated (ATT), with bootstrap standard errors in parentheses. *, **, and *** indicate significance at the 10, 5, and 1% levels, respectively. Radius matching uses a radius of 0.05, and caliper matching uses a caliper of 0.01.

TABLE 6 IV–CMP regression results.

Variable	First stage	Second stage
	Digital payment	Finance formalization
Digital payment		0.264** (0.103)
Mobile internet access	0.950*** (0.100)	
Control variables	Yes	Yes
Province fixed effects	Yes	Yes
Year fixed effects	Yes	Yes
Observations	3,494	3,494

*, **, and *** indicate significance at the 10, 5, and 1% levels, respectively.

TABLE 7 Test results for individual-mean variables.

Individual-mean variable	Coefficient	Std. error	z-statistic	*p*-value
Digital payment_mean	−0.169	0.758	−0.220	0.823
Age_mean	0.161	0.128	1.260	0.207
Health status_mean	0.334	0.248	1.350	0.177
Years of education_mean	−0.034	0.144	−0.240	0.812
Household size_mean	−0.158	0.219	−0.720	0.469
Household wage income_mean	−0.677	0.437	−1.550	0.121
Household net income_mean	−0.095	0.390	−0.240	0.808
Major household shock_mean	0.414	0.439	0.940	0.346
χ^2	5.727	–	–	–
p-value	0.678	–	–	–

TABLE 8 Pooled ordered probit results.

Variable	Oprobit	1	2	3
	(1)	(2)dy/dx	(3)dy/dx	(4)dy/dx
Digital payment	0.207** (0.094)	−0.006** (0.003)	−0.019** (0.008)	0.024** (0.011)
Wald	35.850***	–	–	–
Log likelihood	−877.158	–	–	–
Observations	3,494	3,494	3,494	3,494

*, **, and *** indicate significance at the 10, 5, and 1% levels, respectively. All models control for individual and household characteristics as well as province and year fixed effects. Columns (1)–(3) report marginal effects.

TABLE 9 Robustness check with an alternative dependent variable.

Variable	Finance formalization		
	(1) Pooled logit	(2) Random-effects logit	(3) Fixed-effects logit
Digital payment	0.009* (0.006)	0.009* (0.005)	0.007 (0.012)
Control variables	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Province fixed effects	Yes	Yes	Yes
Observations	3,494	3,494	139
Pseudo R^2	0.038	–	–
Log pseudolikelihood	−197.187	−191.857	−11.023
Sigma_u	–	2.461	–
Rho	–	0.648	–
LR test	–	10.660***	–
Hausman test	–	–	0.997

*, **, and *** indicate significance at the 10, 5, and 1% levels, respectively. Standard errors are reported in parentheses, and all reported coefficients are average marginal effects.

4.4 Mechanism analysis

Building on the foregoing theoretical analysis and empirical findings, we next examine whether digital payment promotes finance formalization by strengthening formal borrowing preference and improving access to financial products. To avoid the problems of high collinearity, reverse causality, and measurement error between the treatment and mediating variables—which can weaken statistical power and bias estimates—we directly estimate the impact of digital payment on formal borrowing preference and access to financial products.

Column (1) of Table 10 shows that the coefficient on digital payment is positive and statistically significant, indicating that the use of digital payment significantly increases the likelihood that households identify banks or other formal financial institutions as their preferred borrowing source. In other words, digital payment reshapes households' credit preferences in favor of formal lenders, thereby supporting the finance-formalization channel posited in H2. Column (2) reports the effect of digital payment on access to financial products, with a positive and

statistically significant coefficient. This implies that digital payment significantly raises the probability that a household holds at least one formal financial product (such as deposits, insurance, wealth-management products, or formal loans), and thus further promotes the formalization of rural household finance. Hypothesis H3 is therefore supported.

Consistent with the theoretical discussion above, we then use Equation 4 to evaluate the moderating role of household financial vulnerability. For brevity, Table 11 reports only the coefficients on digital payment, financial vulnerability, and their interaction term. The estimated coefficients on digital payment and financial vulnerability both conform to expectations. The coefficient on digital payment is positive and statistically significant, in line with previous results. The coefficient on household financial vulnerability is significantly negative, indicating that more financially vulnerable households are, on average, less likely to use formal borrowing. Crucially, the interaction term between digital payment and financial vulnerability is positive and statistically significant, suggesting that the positive effect of digital payment on finance formalization is stronger for more financially vulnerable households. This pattern is consistent with H4.

TABLE 11 Moderating effect of household financial vulnerability.

Variable	Finance formalization
Digital payment	0.308**(0.148)
Financial vulnerability	−0.368**(0.166)
Digital payment × financial vulnerability	0.286**(0.135)
Control variables	Yes
Province fixed effects	Yes
Year fixed effects	Yes
Wald test	47.910
Log likelihood	−836.615
Observations	3,494

Standard errors are reported in parentheses. ***, **, and * indicate significance at the 1, 5, and 10% levels, respectively.

4.5 Heterogeneity analysis

4.5.1 Gender heterogeneity

As shown in Table 12, digital payment significantly promotes finance formalization among male-headed households (coefficient = 0.441, $p < 0.05$), whereas the effect is statistically insignificant for female-headed households. One plausible explanation is that men typically play a more dominant role in household financial decision-making, have higher acceptance and more frequent use of digital payment, and are therefore better positioned to leverage its advantages in accessing formal finance. In addition, men often exhibit greater risk tolerance and maintain broader social networks, which may help them capitalize more effectively on the financial conveniences brought by digital payment.

4.5.2 Regional heterogeneity

Table 12 also shows that digital payment has a significant positive effect on finance formalization for households in the eastern region (coefficient = 0.534, $p < 0.05$), while the effect is insignificant for households in the central and western regions. This divergence likely reflects differences in digital and financial infrastructure: eastern China has more advanced digital infrastructure, denser networks of financial institutions, and higher awareness and acceptance of digital financial services among rural households. By contrast, in the central and western regions, digital divides and limited coverage of formal financial services constrain the extent to which digital payment can promote a shift toward formal financing channels.

TABLE 10 Regression results for the mediation mechanism.

Variable	Formal borrowing preference	Access to financial products
Digital payment	0.394* (0.154)	0.155* (0.046)
Control variables	Yes	Yes
Province fixed effects	Yes	Yes
Year fixed effects	Yes	Yes
Wald test	178.600	1449.200
Log likelihood	−1907.5508	−251.8647
Observations	3,494	3,494

*, **, and *** indicate significance at the 10, 5, and 1% levels, respectively. Standard errors are reported in parentheses.

4.5.3 Income heterogeneity

Finally, when the sample is split at the median income, the estimates in Table 12 indicate that digital payment significantly promotes finance formalization among lower-income households, suggesting a stronger impact at the lower end of the income distribution. This finding is consistent with the inclusive finance nature of digital payment: by lowering the barriers to accessing financial services, digital payment creates new opportunities for low-income households—who are often underserved by traditional finance—to connect with formal financial institutions and gradually formalize their borrowing behavior.

5 Conclusions and policy implications

5.1 Conclusion

Using four waves (2016–2022) of CFPS panel data on landholding households defined by contracted and operational land rights, this paper examines how digital payment affects the formalization of rural household finance and through which mechanisms this effect operates. The main conclusions are as follows.

First, digital payment is a key driver of finance formalization among rural households. Baseline regression results show that the use of digital payment significantly increases the probability of borrowing from banks and other formal financial institutions. This core result remains robust to alternative specifications, PSM, and IV estimations, indicating that the findings are reliable. Against the backdrop of a rural credit "double bind," digital payment—as a representative fintech innovation—has become an effective channel for shifting

TABLE 12 Heterogeneity analysis results.

Variable	Finance formalization					
	Male	Female	Eastern	Central and western	High income	Low income
Digital payment	0.441** (0.199)	0.059 (0.255)	0.534** (0.252)	0.098 (0.212)	0.191 (0.184)	0.670* (0.348)
Log likelihood	−512.273	−318.435	−412.510	−417.730	−413.730	−431.657
Observations	2074	1,420	1992	1,502	1747	1747

***, **, and * indicate significance at the 1, 5, and 10% levels, respectively. All regressions control for individual and household characteristics, as well as province and year fixed effects.

household borrowing from informal to formal finance. Second, digital payment operates through dual demand- and supply-side mechanisms. On the demand side, digital payment enhances financial literacy and digital trust, reshaping households' borrowing preferences and increasing their propensity to use formal financing channels. On the supply side, digital payment improves the accessibility of financial services by relaxing geographic constraints and lowering transaction costs. It also enables financial institutions to adopt big-data-based risk management and helps alleviate information asymmetries that have historically constrained lending to land-based producers.

Third, the inclusive-finance effect of digital payment is particularly pronounced among financially vulnerable households. For households with unstable income, limited savings, and weak risk-coping capacity, the financing improvements associated with digital payment are especially strong. Having long been excluded from the formal financial system and heavily reliant on high-cost informal lenders, these vulnerable households are more likely to shift toward formalized borrowing patterns once digital payment allows their "digital credit" to be recognized by formal institutions. Fourth, the impact of digital payment on finance formalization exhibits marked heterogeneity across groups and regions. The positive effect is stronger for male-headed households, households in eastern China, and lower-income households, while the effect is weaker or statistically insignificant for female-headed households and those located in central and western regions.

A limitation is that our measure of finance formalization is based on the household's main borrowing source, and thus cannot fully reflect more complex borrowing arrangements, such as multiple concurrent loans, heterogeneous borrowing motives (e.g., production versus consumption), or finer distinctions between formal and semi-formal providers. Our results should therefore be interpreted as evidence on the formalization of households' primary borrowing channel, rather than a complete characterization of portfolio-level borrowing structures.

5.2 Policy implications

These conclusions give rise to several policy implications. More broadly, the findings also inform China's rural revitalization and land transfer agenda: by facilitating a shift toward formal borrowing, digital payment can support productive investment in land-based agriculture; and as land transfer becomes more prevalent, it can improve the traceability of transactions and cash flows, easing information frictions in formal lending for land operators.

(1) Strengthen rural digital infrastructure and narrow the digital divide. The ability of digital payment to encourage a shift toward formal finance hinges on reliable and convenient digital network access and a sufficiently broad user base. Governments should continue to treat rural information infrastructure as a key public good, accelerate the rollout of 5G networks and high-speed broadband in rural areas, and improve the effective coverage and stability of digital payment services among landholding households.

(2) Encourage innovation in risk management and unlock the value of digital credit. The core value of digital payment lies in making households' implicit credit observable. Regulators can introduce incentive-compatible policies to encourage commercial banks, rural credit cooperatives, and other institutions to cooperate with fintech firms, develop big-data credit scoring models based on digital footprints, and incorporate these models into loan approval processes for households engaged in land-based production and investment.

(3) Design targeted inclusive financial products for financially vulnerable households. The empirical results highlight strong positive effects of digital payment for financially vulnerable and low-income households. Financial institutions should take this as an opportunity to fulfill their social responsibilities by designing more inclusive financial products tailored to the needs and risk profiles of these groups—such as small, flexible credit lines linked to digital payment histories—thereby lowering access thresholds and supporting both sustainable land use and livelihood improvement.

(4) Adopt differentiated strategies to fully exploit the advantages of digital payment. Because the positive impact of digital payment is stronger for men, eastern-region households, and low-income farmers, but weaker for women and for households in central and western regions, policy design should incorporate explicit targeting. For groups and regions where the effect is relatively weak, supportive measures—such as digital literacy training for women, subsidies for rural network access, and pilot programs for digital finance in less-developed areas—can help ensure a more equitable distribution of the benefits of digitalization and enhance the overall contribution of digital payment to the formalization of rural household finance.

Data availability statement

Publicly available datasets were analyzed in this study. The data come from the China Family Panel Studies (CFPS), a nationally representative longitudinal survey administered by Peking University.

CFPS data can be accessed by registered researchers via the official data portal (http://www.isss.pku.edu.cn/cfps/en/) in accordance with the project's data use policies.

Ethics statement

Ethical approval was not required for the study involving humans in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and the institutional requirements.

Author contributions

JW: Writing – review & editing, Writing – original draft. CS: Writing – review & editing. JJ: Writing – review & editing. YW: Writing – review & editing. XZ: Writing – review & editing, Writing – original draft.

Funding

The author(s) declared that financial support was not received for this work and/or its publication.

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

References

Allen, F., Demirgüç-Kunt, A., Klapper, L., and Martínez Pería, M. S. (2016). The foundations of financial inclusion: understanding ownership and use of formal accounts. *J. Financ. Intermed.* 27, 1–30. doi: 10.1016/j.jfi.2015.12.003

Ayyagari, M., Demirgüç-Kunt, A., and Maksimovic, V. (2010). Formal versus informal finance: evidence from China. *Rev. Financ. Stud.* 23, 3048–3097. doi: 10.1093/rfs/hhq030

Beck, T., Demirgüç-Kunt, A., and Martínez Pería, M. S. (2007). Reaching out: access to and use of banking services across countries. *J. Financ. Econ.* 85, 234–266. doi: 10.1016/j.jfineco.2006.07.002

Berg, T., Burg, V., Gombović, A., and Puri, M. (2020). On the rise of FinTechs: credit scoring using digital footprints. *Rev. Financ. Stud.* 33, 2845–2897. doi: 10.1093/rfs/hhz099

Björkegren, D., and Grissen, D. (2020). Behavior revealed in mobile phone usage predicts credit repayment. *World Bank Econ. Rev.* 34, 618–634. doi: 10.1093/wber/lhz006

Chai, S., and Qi, H. (2025). Mobile payments and households' over-indebtedness: Micro evidence based on subjective and objective perspectives. *SAGE Open* 15:78. doi: 10.1177/21582440251388078

Chen, B., and Xiao, J. (2025). Digital payments enhance both formal and informal credit access for rural households: evidence from China. *Front. Sustain. Food Syst.* 9:1676462. doi: 10.3389/fsufs.2025.1676462

Chen, Z., Li, X., Zhang, J., and Xia, X. (2024). Does digital finance alleviate household consumption inequality? Evidence from China. *Financ. Res. Lett.* 60:104844. doi: 10.1016/j.frl.2023.104844

Chyi, H., and Mao, S. (2012). The Determinants of Happiness of China's Elderly Population. *J. Happiness Stud.* 13:167–185. doi: 10.1007/s10902-011-9256-8

Cole, S., Sampson, T., and Zia, B. (2011). Prices or knowledge? What drives demand for financial services in emerging markets? *J. Finance* 66, 1933–1967. doi: 10.1111/j.1540-6261.2011.01696.x

Conning, J., and Udry, C. (2007). "Rural financial markets in developing countries" in Handbook of Agricultural Economics. Agricultural Development: Farmers, Farm Production and Farm Markets. eds. R. Evenson and P. Pingali, vol. 3 (Amsterdam: Elsevier), 2857–2908. doi: 10.1016/S1574-0072(06)03056-8

Dai, L., and Wang, Y. (2022). The boosting effect of digital finance on rural residents' consumption based on empirical data from the 2017 China household finance survey. *BCP Bus. Manag* 25:1774. doi: 10.54691/bcpbm.v25i.1774

Ding, S., Ruan, Y., and Dou, L. (2025). Rural residents' digital payment: the use and its impact on credit availability – evidence using extended UTAUT2. *SAGE Open* 15, 1–21. doi: 10.1177/21582440251321861

Dong, F., Lu, J., and Featherstone, A. M. (2010). Effects of credit constraints on household productivity in rural China (working paper no. 10-WP 516). Center for Agricultural and Rural Development. Ames, IA: Iowa State University.

Dong, F., Lu, J., and Featherstone, A. M. (2012). Effects of credit constraints on household productivity in rural China. *Agric. Financ. Rev.* 72, 402–415. doi: 10.1108/00021461211277259

Greene, W. H. (2012). Econometric analysis. 7th Edn. Upper Saddle River, NJ: Prentice Hall.

Imai, K., Keele, L., and Tingley, D. (2010). A general approach to causal mediation analysis. *Psychol. Methods* 15, 309–334. doi: 10.1037/a0020761

Jack, W., and Suri, T. (2014). Risk sharing and transactions costs: evidence from Kenya's mobile money revolution. *Am. Econ. Rev.* 104, 183–223. doi: 10.1257/aer.104.1.183

Khan, F. U., Nouman, M., Negrut, L., Abban, J., Cismas, L. M., and Siddiqi, M. F. (2024). Constraints to agricultural finance in underdeveloped and developing countries: a systematic literature review. *Int. J. Agric. Sustain.* 22:2329388. doi: 10.1080/14735903.2024.2329388

Kong, S. T., and Loubere, N. (2021). Digitally down to the countryside: Fintech and rural development in China. *J. Dev. Stud.* 57, 417–435. doi: 10.1080/00220388.2021.1919631

Li, J., Wu, Y., and Xiao, J. J. (2020). The impact of digital finance on household consumption: evidence from China. *Econ. Model.* 86, 317–326. doi: 10.1016/j.econmod.2019.09.027

Lin, L., Wang, W., Gan, C., Cohen, D. A., and Nguyen, Q. T. (2019). Rural credit constraint and informal rural credit accessibility in China. *Sustainability* 11:1935. doi: 10.3390/su11071935

Liu, S., Carter, M. R., and Yao, Y. (1998). Dimensions and diversity of property rights in rural China: Dilemmas on the road to further reform. *World Dev.* 26:1789–1806. doi: 10.1016/S0305-750X(98)00088-6

Liu, J., Chen, Y., Chen, X., and Chen, B. (2024a). Digital financial inclusion and household financial vulnerability: an empirical analysis of rural and urban disparities in China. *Heliyon* 10:e35540. doi: 10.1016/j.heliyon.2024.e35540

Liu, Z., Li, X., and Li, Z. (2024b). Inclusive FinTech, open banking, and bank performance: evidence from China. *Financ. Innov.* 10:149. doi: 10.1186/s40854-024-00679-3

Lusardi, A., Schneider, D. J., and Tufano, P. (2011). Financially fragile households: evidence and implications. *Brook. Pap. Econ. Act.* 2011, 83–134. doi: 10.1353/eca.2011.0002

MacKinnon, D. P., Fairchild, A. J., and Fritz, M. S. (2007). Mediation analysis. *Annu. Rev. Psychol.* 58, 593–614. doi: 10.1146/annurev.psych.58.110405.085542

Meyll, T., and Walter, A. (2019). Tapping and waving to debt: mobile payments and credit card behavior. *Financ. Res. Lett.* 28, 407–413. doi: 10.1016/j.frl.2018.06.009

Mundlak, Y. (1978). On the pooling of time series and cross section data. *Econometrica* 46, 69–85. doi: 10.2307/1913646

Ozili, P. K. (2018). Impact of digital finance on financial inclusion and stability. *Borsa Istanb. Rev.* 18, 329–340. doi: 10.1016/j.bir.2017.12.003

Roodman, D. (2011). Fitting fully observed recursive mixed-process models with CMP. *Stata J.* 11, 159–206. doi: 10.1177/1536867X1101100202

Shao, Z., Zhang, L., Li, X., and Guo, Y. (2019). Antecedents of trust and continuance intention in mobile payment platforms in China: the moderating roles of trust propensity and risk attitude. *Electron. Commer. Res. Appl.* 33:100823. doi: 10.1016/j.elerap.2018.100823

Shen, Y. (2025). Digital financial inclusion and income inequality in China. IMF working paper no. 25/71. Washington, DC: International Monetary Fund.

Stiglitz, J. E., and Weiss, A. (1981). Credit rationing in markets with imperfect information. *Am. Econ. Rev.* 71, 393–410.

Suri, T., and Jack, W. (2016). The long-run poverty and gender impacts of mobile money. *Science* 354, 1288–1292. doi: 10.1126/science.aah5309

Turvey, C. G., and Kong, R. (2010). Informal lending amongst friends and relatives: can microcredit compete in rural China? *China Econ. Rev.* 21, 544–556. doi: 10.1016/j.chieco.2010.05.001

Turvey, C. G., Kong, R., and Huo, X. (2010). Borrowing amongst friends: the economics of informal credit in rural China. *China Agric. Econ. Rev.* 2, 133–147. doi: 10.1108/17561371011044261

Wang, X., and Wang, X. (2022). Digital financial inclusion and household risk sharing: evidence from China's digital finance revolution. *China Econ. Q. Int.* 2, 334–348. doi: 10.1016/j.ceqi.2022.11.006

Wang, X., Li, X., and Zhou, H. (2025). Digital finance use and household consumption inequality: evidence from rural China. *Rev. Dev. Econ.* 29, 1344–1360. doi: 10.1111/rode.13194

Wen, C., Xiao, Y., and Hu, B. (2024). Digital financial inclusion, industrial structure and urban–rural income disparity: evidence from Zhejiang Province, China. *PLoS One* 19:e0303666. doi: 10.1371/journal.pone.0303666

Wooldridge, J. M. (2010). Econometric analysis of cross section and panel data. 2nd Edn. Cambridge, MA: MIT Press.

World Bank (2008). World development report 2008: Agriculture for development. Washington, DC: World Bank.

Xie, Y., and Hu, J. (2014). An introduction to the China family panel studies (CFPS). *Chin. Sociol. Rev.* 47, 3–29. doi: 10.2753/CSA2162-0555470101.2014.11082908

Yan, Y., Chen, L., Zhou, Z., and Wei, Y. (2025). Digital financial inclusion and agricultural modernization development in China—a study based on the perspective of agricultural mechanization services. *Humanit. Soc. Sci. Commun.* 12, 1–11. doi: 10.1057/s41599-025-04821-z

Yu, C., Jia, N., Li, W., and Wu, R. (2022). Digital inclusive finance and rural consumption structure—evidence from Peking University digital inclusive financial index and China household finance survey. *China Agric. Econ. Rev.* 14, 165–183. doi: 10.1108/CAER-10-2020-0255

Zeller, M., and Sharma, M. (1998). "Rural finance and poverty alleviation" in Food Policy Report (Washington, DC: International Food Policy Research Institute).

Zhang, Z. (2022). Research on the impact of digital finance on China's urban–rural income gap. *Rev. Econ. Assess.* 1:5. doi: 10.58567/rea01010005

Zhao, P., Zhang, W., Cai, W., and Liu, T. (2022). The impact of digital finance use on sustainable agricultural practices adoption among smallholder farmers: evidence from rural China. *Environ. Sci. Pollut. Res.* 29, 39281–39294. doi: 10.1007/s11356-022-18939-z