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Are Digital Skills and Financial Knowledge Complementary? Evidence from Older Households' Asset Allocation in China

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Abstract: Data from the 2019 and 2021 waves of the China Household Finance Survey were used to examine whether digital skills and financial knowledge jointly shape financial asset diversification among Chinese households headed by adults aged 60 years or older. Digital skills were measured by smartphone use and third-party mobile-payment-account adoption, financial knowledge by correct responses to interest-rate and inflation questions, and capability complementarity by the interaction between the two standardized indices. Pooled ordinary least squares models with province and year fixed effects, temporal-prediction specifications, inverse-probability weighting, and alternative measurement and sample checks were estimated. Digital skills, financial knowledge, and their interaction were positively associated with diversification. In the preferred specification, the corresponding coefficients were 0.0134, 0.0118, and 0.0167, respectively, and all were significant at the 1% level. Capability complementarity was concentrated in broader portfolio scope: dual-enablement households were more likely to form multi-asset portfolios and less likely to hold only cash and bank deposits, with significant super additive increments. The association was stronger among households willing to accept some risk and weaker among households residing in rural areas whose heads held agricultural hukou status. The findings indicate that digital operational competence and financial judgment function as complementary capabilities and support integrating digital-skills training with financial education for older adults.

Keywords: Digital Skills; Financial Knowledge; Older Households; Household Asset Allocation

1. Introduction

As smartphones, mobile payments, and online financial services become increasingly embedded in everyday life, households are changing how they obtain information, compare products, and execute transactions. Digitalization reduces some transaction costs, but it also transfers more screening, judgment, and operational tasks to households. The ability to use digital tools is not equivalent to the ability to make appropriate financial decisions. For groups

with relatively limited digital skills and financial knowledge, a gap may therefore persist between the availability of digital services and the capacity to use them effectively.

This issue is particularly salient for older households. Compared with working-age households, older households are more likely to be in a phase of wealth preservation and gradual decumulation. Their income-growth prospects are relatively limited, while uncertainty related to medical expenses, caregiving, and retirement remains substantial. They therefore place greater weight on capital preservation, liquidity, and risk control. Existing studies show that retirement, health status, and risk attitudes affect household asset choice [1–4]. At the same time, online financial services require users to operate devices, complete identity verification, screen information, and assess risks. Market participation alone is therefore insufficient to characterize older households' asset allocation in a digital environment.

Existing research on digitalization and household finance has developed along three main lines. First, the internet and digital finance can reduce information-search and transaction-execution costs, thereby affecting financial-market participation and household asset allocation [5–7]. Second, financial knowledge shapes households' ability to interpret returns, risks, and inflation and, in turn, affects market participation and portfolio choice [8–10]. Third, as research on the digital divide has shifted from access to effective use, individual digital skills have become increasingly important for understanding household financial behavior [11–15].

Important gaps nevertheless remain. First, many studies rely on macro-level digital-finance indices, internet access, or digital-product use, which do not directly capture whether households can complete basic digital operations. Second, digital skills and financial knowledge are often examined separately, whereas less attention has been paid to whether operational competence and financial judgment jointly shape household financial asset allocation. Third, the literature often focuses on stock-market participation, risky-asset ownership, or risky-asset shares, while devoting less attention to whether households can move beyond deposit concentration and form multi-asset portfolios. This study refers to that process as prudent diversification: broadening the scope of formal financial assets within the household's risk-bearing capacity rather than indiscriminately increasing risky-asset exposure.

Using the 2019 and 2021 waves of the China Household Finance Survey (CHFS), this study examines the associations between digital skills, financial knowledge, their complementarity, and financial asset diversification among households headed by adults aged 60 or older. Digital skills are measured by smartphone use and the opening of at least one third-party mobile-payment account. Financial knowledge is measured by responses to questions on interest rates and inflation. To avoid a mechanical association arising from overlapping measurement, balances in third-party payment accounts and internet wealth-management products are excluded from the formal financial-asset portfolio. The diversification index is constructed from six asset classes: cash and bank deposits; bonds and conservative funds; stocks and equity-oriented assets; regulated wealth-management products; derivatives; and gold. The index captures concentration across asset classes rather than investment performance.

The results show that digital skills, financial knowledge, and their interaction are all positively associated with financial asset diversification among older households. Further analysis indicates that the key margin of capability complementarity lies in helping households move beyond single-asset holdings: households in the dual-enablement profile are markedly more likely than dual-constraint households to form multi-asset portfolios and, among

households holding included assets, are less likely to hold only cash and deposits. Probability-scale tests of super additivity provide additional evidence consistent with capability complementarity. Year-specific estimates, temporal-prediction specifications, inverse-probability weighting, alternative asset classifications, sample-structure checks, and additional controls all support the main findings. The complementarity association is stronger among households willing to accept some risk and weaker among households residing in rural areas whose heads hold agricultural hukou status. Hukou refers to China's household-registration status.

This study contributes in three respects. First, it places digital operational competence and financial judgment within a unified framework and examines whether the two capabilities work jointly, thereby extending micro-level explanations of household financial behavior in a digital environment. Second, it moves beyond general market participation to financial asset diversification, focusing on whether older households reduce excessive dependence on deposits and form multi-asset portfolios. Third, it distinguishes the key margin of capability complementarity from the conditions that shape its conversion into portfolio outcomes: the association is concentrated in broader portfolio scope, while its strength varies with risk attitudes and the joint condition of rural residence and agricultural hukou status. The remainder of the article reviews the literature and develops the hypotheses, presents the research design, reports the baseline results, discusses robustness and endogeneity, examines the key mechanism and heterogeneity, and concludes.

2. Literature Review and Hypothesis Development

2.1. Household Financial Asset Allocation: From Limited Participation to Portfolio Diversification

Research on household financial asset allocation initially centered on the limited-participation puzzle. Although equities and other risky assets have delivered relatively high average returns over long horizons, many households remain outside risky financial markets. Income risk, entry costs, borrowing constraints, risk preferences, and trust can all suppress stock ownership [16,17]. Fixed participation costs further explain heterogeneity in household portfolios [18]. Campbell [19] showed that household financial decisions often diverge from benchmark portfolio theory. Together, these studies provide a foundation for understanding why many households remain concentrated in a small number of familiar assets.

In China, financial-service accessibility, financial knowledge, wealth accumulation, and institutional arrangements also shape household asset structures. Financial accessibility affects both market participation and asset choice [20]. Financial knowledge and wealth accumulation influence portfolio composition [21], while social pension insurance and housing provident funds alter household asset allocation [22,23]. Subjective expectations of uncertainty also affect allocation behavior [24]. Household portfolios are therefore jointly shaped by resource endowments, institutional conditions, and cognitive capabilities.

Older households place particular emphasis on capital safety and stable cash flows. According to the life-cycle hypothesis, retirement changes the expected paths of labor income and consumption and thereby induces portfolio rebalancing. Households adjust equity exposure after retirement [1], while health changes and risk attitudes also shape household asset choice [24,25]. Evaluating older households' allocation should therefore not rest on the

premise that higher equity weights are always preferable. The more relevant question is whether households can reduce excessive concentration in a single asset category while keeping risks manageable.

This perspective shifts the focus from whether households participate to how they allocate. Households may incur losses both by remaining outside risky-asset markets and by holding under-diversified portfolios after entry [26]. Low financial literacy is associated with insufficient diversification [27]. Chinese studies have examined household portfolio effectiveness, portfolio risk, and the role of financial literacy [10,28,29]. Rather than directly evaluating investment performance, this study focuses on diversification across formal financial assets and asks whether older households move from deposit concentration toward a broader portfolio structure.

2.2. Digital Finance, Individual Digital Skills, and the Digital Divide among Older Adults

Digital technologies change how households access financial information and complete transactions. Internet use is associated with stock-market participation [5]. Quasi-experimental evidence from broadband expansion shows that internet access can increase stock-market participation, mutual-fund ownership, and portfolio diversification [30]. In China, studies have examined the effects of digitalization on risky financial investment, portfolio effectiveness, and household financial asset allocation [6,7,31,32]. Overall, digitalization creates new channels through which households can access formal financial assets.

As the literature has developed, researchers have increasingly distinguished the digital environment from individual digital skills. The concept of the second-level digital divide emphasizes that internet access does not guarantee effective use [15]. Digital skills encompass not only device operation but also information management and problem solving [33,34]. In household finance, smartphone use, mobile-payment-account adoption, and experience with online operations are therefore more closely related than internet access alone to the ability to convert digital tools into actual behavior.

Chinese research increasingly incorporates digital competence into household-finance analysis. Digital capabilities broaden and deepen participation in risky financial markets [12]. Digital literacy is associated with household financial asset allocation [13], financial-market participation among middle-aged and older adults [11], and portfolio effectiveness [14]. These findings imply that the financial consequences of digitalization cannot be assessed solely by whether services are available; households must also possess the capabilities required to use them.

The effects of digitalization are uneven. Digital-finance use is subject to knowledge and experience thresholds [35], and different households face heterogeneous digital constraints [36,37]. For older households, difficulties with device operation, risk concerns, and limited experience may reinforce one another, creating a disconnect between the availability of digital tools and effective use. Qualitative evidence also documents older adults' concerns about trust, security, privacy, and self-efficacy in digital banking [38].

2.3. Financial Knowledge: From Market Participation to Portfolio Evaluation

Financial knowledge is an internal capability that enables households to translate information into decisions. Individuals with lower financial literacy are substantially less likely

to participate in stock markets [8]. Financial knowledge affects saving, investment, borrowing, and retirement preparation and is therefore an important form of human capital [39,40]. Chinese studies reach similar conclusions: financial knowledge affects household asset choice, financial exclusion, portfolio diversity, and portfolio effectiveness [9,10,41,42].

Financial knowledge matters not only for market entry but also for post-entry portfolio allocation. Cognitive ability is associated with direct and indirect equity holdings [43], and insufficient financial literacy is related to under-diversification [27]. Delegated investment and financial advice can ease some cognitive constraints [44,45], but they cannot fully substitute for a household's ability to understand basic financial concepts.

The digital-finance environment further increases the importance of financial knowledge. On online platforms, households often need to screen information, identify risks, compare returns, and confirm transactions independently. Financial knowledge increases both the probability and breadth of farmers' responses to digital finance [46]. Financial literacy also promotes the use of digital financial products [47,48]. Financial knowledge is therefore not merely a static cognitive attribute; it is an important condition for the prudent use of digital tools.

2.4. Capability Complementarity and Prudent Diversification: Literature Synthesis and Hypotheses

The literature suggests that digital skills and financial knowledge correspond to different stages of household financial decision-making. Digital skills primarily reduce information-acquisition and transaction-execution costs, whereas financial knowledge helps households understand risk-return trade-offs and identify product differences. Without digital skills, knowledge advantages may be difficult to translate into actual operations; without financial knowledge, the use of digital tools may not correspond to more diversified asset allocation. Existing evidence indicates that financial literacy can amplify the financial effects of digital finance or digital literacy [14,37,47]. This study therefore focuses on whether the two capabilities exhibit a complementary association.

H1. Complementarity between digital skills and financial knowledge is positively associated with financial asset diversification among older households.

Capability complementarity may first be reflected in broader portfolio scope. Fixed participation costs, information costs, and comprehension costs can keep households concentrated in familiar assets such as cash and deposits [16,18]. Digital skills facilitate information access and operational execution, while financial knowledge helps households understand product differences. Together, the two capabilities may enable households to move from deposit-only allocation to multi-asset portfolios. Related studies show that internet use and digital competence are associated with risky financial-market participation [6,12], while financial knowledge broadens responses to digital finance [46].

H2. Complementarity between digital skills and financial knowledge is associated with a lower probability of holding only cash and bank deposits and a higher probability of forming a multi-asset portfolio.

The association between capability complementarity and diversification may also vary with household risk attitudes and the joint condition of rural residence and agricultural hukou status. Highly risk-averse households may continue to choose familiar low-risk assets even when they possess relevant knowledge and skills. Households residing in rural areas whose

heads hold agricultural hukou status may also face stronger overall constraints, making it more difficult for capability advantages to translate into broader portfolios.

H3. The positive association between digital-skills–financial-knowledge complementarity and diversification is stronger among households willing to accept some risk and weaker among households residing in rural areas whose heads hold agricultural hukou status.

These arguments imply that capability complementarity does not automatically translate into improved allocation independently of household conditions. The heterogeneity analyses therefore examine how the association varies with risk attitudes and the joint rural-residence–agricultural-hukou condition.

3. Materials and Methods

3.1. Data Source and Sample Construction

The analysis uses the 2019 and 2021 waves of the China Household Finance Survey (CHFS). Households headed by adults aged 60 or older are classified as older households. Observations are excluded when asset amounts cannot be identified or key variables are missing. Missing liabilities are coded as zero and accompanied by a missing-liability indicator. After balances in third-party payment accounts and internet wealth-management products are excluded, households with no remaining included formal financial assets are removed from the baseline sample. The final sample contains 18,947 household-year observations: 12,138 in 2019 and 6,809 in 2021, representing 15,724 distinct households. A larger sample of 21,739 observations with complete covariates is retained for formal-financial-market-entry analyses.

3.2. Variable Definitions and Measurement

Outcome variable: The financial asset diversification index (PortfolioDiv) measures the diversification of households' formal financial assets. Based on the economic properties of the accounts reported in the CHFS, formal financial assets are grouped into six classes: cash and bank deposits; bonds and conservative funds; stocks and equity-oriented assets; regulated wealth-management products; derivatives; and gold. Let A_{kit} denote the amount held by household i in asset class k in year t , and let w_{kit} denote the corresponding portfolio weight:

$$w_{kit} = A_{kit} / (\sum_{k=1}^6 A_{kit}) \quad (1)$$

$$\text{PortfolioDiv}_{it} = 1 - \text{HHI}_{it} = 1 - \sum_{k=1}^6 w_{kit}^2 \quad (2)$$

A higher PortfolioDiv value indicates less dependence on a single asset class and a broader allocation across financial assets. This measure should be interpreted as the inverse of asset-class concentration rather than as a direct measure of investment performance or household welfare. Compared with performance measures that rely on external return assumptions, it is better suited to identifying whether older households reduce dependence on deposits and broaden their holdings of formal financial assets.

Core explanatory variables: Digital skills refer to the basic operational capabilities required to use digital tools in financial activities. Financial knowledge refers to the domain-specific cognitive capacity required to identify basic risk-return relationships. The digital-skills index sums two binary items: whether the household head uses a smartphone and whether the household has opened at least one third-party mobile-payment account. The index ranges from

0 to 2. The financial-knowledge index sums correct responses to questions on interest rates and inflation and also ranges from 0 to 2. The two indices are standardized in the pooled core sample of older household heads from the 2019 and 2021 waves, and their interaction is used as the complementarity term:

$$\text{Synergy}_{it} = Z(\text{DigitalSkills}_{it}) \times Z(\text{FinancialKnowledge}_{it}) \quad (3)$$

Digital skills correspond primarily to information acquisition and operational execution, whereas financial knowledge corresponds primarily to product comprehension and risk judgment. Including the two variables and their interaction in the same model allows us to examine whether operational competence and financial judgment exhibit a complementary association [6,12,39].

Table 1. Definitions and measurement of the core variables.

Variable category	Variable	Survey item or construction basis	Coding rule
Outcome	Portfolio diversification index (PortfolioDiv)	Six classes of formal financial assets: (1) cash and bank deposits; (2) bonds and conservative funds; (3) stocks and equity-oriented assets; (4) regulated wealth-management products; (5) derivatives; and (6) gold.	Let w_k denote the weight of class k . $HHI = \sum w_k^2$; $\text{PortfolioDiv} = 1 - HHI$. The range is 0–5/6; higher values indicate greater diversification.
Core explanatory variable	Digital skills	Smartphone use and the opening of at least one third-party mobile-payment account. 2019: G1009a and D7106d. 2021: G1009a and D7106d_1_mc–D7106d_6_mc.	Smartphone use=1, otherwise 0. Opening of at least one third-party payment account=1, otherwise 0. The sum ranges from 0 to 2.
Core explanatory variable	Financial knowledge	Both waves use: H3105: interest-rate calculation. H3106: understanding inflation.	Each correct answer=1. Incorrect, unknown, or incomputable answers=0. The sum ranges from 0 to 2.
Core explanatory variable	Capability complementarity (Synergy)	Constructed from digital skills and financial knowledge.	After pooling the 2019 and 2021 CHFS waves, both indices are standardized in the core sample of older households: $\text{Synergy} = Z(\text{Digital Skills}) \times Z(\text{Financial Knowledge})$. Strict definition: Digital Skills=2 indicates high digital skills; Financial Knowledge=2 indicates high knowledge.
Supplementary variable	Four capability profiles (Synergy4)	Classifies households by high or low digital skills and financial knowledge.	Four profiles are defined: dual constraint, knowledge advantage, skills advantage, and dual enablement.

Control variables: Following the household asset-choice literature [7,9,16], the model includes two groups of controls. Household-head characteristics comprise age and age squared, gender, marital status, years of schooling, and self-reported health status. Household characteristics comprise household size, rural residence, agricultural hukou status, homeownership, business operation, household income, total assets, total liabilities, and a missing-liability indicator. Income, assets, and liabilities are transformed using the inverse hyperbolic sine function to preserve zero-valued observations and reduce the influence of extreme values. The main specification also includes year and province fixed effects. In the heterogeneity analysis, risk attitudes are measured using CHFS item H3104: households selecting “unwilling to assume any risk” are classified as highly risk averse, while the remaining valid responses are classified as willing to accept some risk.

Table 2. Descriptive statistics for the main variables.

Variable	N	Mean	SD	Min.	Max.
Financial asset diversification index	18,947	0.0364	0.1250	0.0000	0.7227
Digital-skills index	18,947	0.8969	0.8288	0.0000	2.0000
Financial-knowledge index	18,947	0.5111	0.7034	0.0000	2.0000
Capability-complementarity term	18,947	0.3373	1.0223	-2.2972	3.0631
Number of financial asset classes	18,947	1.1275	0.4261	1.0000	5.0000
Share of narrowly defined risky financial assets	18,947	0.0150	0.0860	0.0000	1.0000
Age of household head	18,947	69.2601	6.7121	60.0000	104.0000
Years of schooling of household head	18,947	8.2368	3.9605	0.0000	22.0000
Health status of household head	18,947	3.1117	0.9870	1.0000	5.0000
Household size	18,947	2.5505	1.4580	1.0000	16.0000
Rural residence = 1	18,947	0.3716	0.4832	0.0000	1.0000
Agricultural hukou = 1	18,947	0.5016	0.5000	0.0000	1.0000

3.3. Model Specification

To examine the association between capability complementarity and financial asset diversification among older households, the baseline specification uses pooled ordinary least squares (OLS):

$$\text{PortfolioDiv}_{it} = \alpha + \beta_1 \text{ZD}_{it} + \beta_2 \text{ZF}_{it} + \beta_3 \text{Synergy}_{it} + \gamma' X_{it} + \mu_p + \lambda_t + \varepsilon_{it} \tag{4}$$

Here, ZD_{it} and ZF_{it} denote standardized digital skills and financial knowledge, respectively; Synergy_{it} is their interaction; X_{it} is the vector of controls; and μ_p and λ_t denote province and year fixed effects. A positive β_3 indicates that simultaneous improvements in digital skills and financial knowledge are associated with greater financial asset diversification. Because some households appear in both survey waves, standard errors are clustered at the household level.

First, the 2019 capability measures are used to predict financial asset diversification in 2021. A stricter specification additionally controls for the household’s 2019 PortfolioDiv:

$$\text{PortfolioDiv}_{i,2021} = \alpha + \beta_1 \text{ZD}_{i,2019} + \beta_2 \text{ZF}_{i,2019} + \beta_3 \text{Synergy}_{i,2019} + \rho \text{PortfolioDiv}_{i,2019} + \gamma' X_{i,2019} + \mu_p + \varepsilon_i \tag{5}$$

Beyond the baseline regression, the analysis evaluates robustness to temporal ordering, random permutation, sample selection, alternative measurement, and sample structure. Specifically, the 2019 capability measures are used to predict 2021 diversification, with an additional specification controlling for baseline diversification; the complementarity term is

randomly permuted 500 times within year-by-province cells; households outside the formal-financial-asset sample are included in an expanded candidate sample, and inverse-probability weights are constructed from Probit estimates of entry probabilities; asset classifications, minimum-balance thresholds, and the construction of the complementarity term are varied; and the models are re-estimated in a balanced panel and a stable-household-head proxy sample.

To identify the relationship between capability complementarity and portfolio scope, the analysis examines two connected margins. The first is whether households form multi-asset portfolios. The second is whether households that already hold included assets remain concentrated exclusively in cash and bank deposits. Households are further classified into four capability profiles—dual constraint, knowledge advantage, skills advantage, and dual enablement—and Probit models are used to estimate adjusted predicted probabilities.

The probability-scale test compares dual-enablement and dual-constraint households and further examines whether “dual enablement – skills advantage – knowledge advantage + dual constraint” differs significantly from zero. Evidence that dual-enablement households are more likely to form multi-asset portfolios, less likely to hold only cash and deposits, and exhibit a significant super additive increment would support a stronger association between joint capabilities and broader portfolio scope.

The ability to translate capability advantages into more diversified allocation may also vary with household risk preferences and the joint condition of rural residence and agricultural hukou status. The heterogeneity analysis therefore introduces an indicator H_{it} for either high risk aversion or the rural-residence–agricultural-hukou condition:

$$\text{PortfolioDiv}_{it} = \alpha + \beta_1 \text{ZD}_{it} + \beta_2 \text{ZF}_{it} + \beta_3 \text{Synergy}_{it} + \delta H_{it} + \eta_1 (\text{ZD}_{it} \times H_{it}) + \eta_2 (\text{ZF}_{it} \times H_{it}) + \eta_3 (\text{Synergy}_{it} \times H_{it}) + \gamma' X_{it} + \mu_p + \lambda_t + \varepsilon_{it} \quad (6)$$

The coefficient η_3 measures the difference in the complementarity association between the constrained and reference groups. The risk-attitude analysis examines whether capability improvements can overcome a preference constraint, while the rural-residence–agricultural-hukou analysis identifies differences in the conversion of capabilities across household structural conditions.

4. Baseline Results

4.1. Baseline Estimates

Table 3 reports the associations of digital skills, financial knowledge, and their interaction with financial asset diversification among older households. The dependent variable is the financial asset diversification index; higher values indicate lower dependence on a single financial asset class and a more diversified portfolio structure. All columns report household-clustered robust standard errors to account for within-household correlation across survey waves.

Columns (1) and (2) examine digital skills and financial knowledge separately. The estimated coefficients are 0.0328 for digital skills and 0.0346 for financial knowledge, both statistically significant at the 1% level. Both digital operational competence and the understanding of basic financial concepts are therefore positively associated with diversification among older households.

Table 3. Digital skills, financial knowledge, and financial asset diversification among older households.

Variable	(1)	(2)	(3)	(4)	(5)	(6)
Digital skills	0.0328*** (0.0011)		0.0238*** (0.0010)	0.0235*** (0.0010)	0.0128*** (0.0010)	0.0134*** (0.0010)
Financial knowledge		0.0346*** (0.0013)	0.0270*** (0.0012)	0.0212*** (0.0010)	0.0124*** (0.0010)	0.0118*** (0.0010)
Digital skills × financial knowledge				0.0169*** (0.0012)	0.0174*** (0.0011)	0.0167*** (0.0011)
Controls	No	No	No	No	Yes	Yes
Year fixed effects	No	No	No	No	No	Yes
Province fixed effects	No	No	No	No	No	Yes
Household clusters	15,724	15,724	15,724	15,724	15,724	15,724
Observations	18,947	18,947	18,947	18,947	18,947	18,947
R ²	0.0691	0.0804	0.1128	0.1297	0.1867	0.1987

Column (3) includes digital skills and financial knowledge simultaneously. The coefficient on digital skills declines from 0.0328 to 0.0238, while the coefficient on financial knowledge declines from 0.0346 to 0.0270; both remain significant at the 1% level. The two capabilities are related, but each retains independent explanatory power: digital skills primarily capture the ability to operate digital tools, whereas financial knowledge primarily captures the ability to interpret basic financial information.

Column (4) adds the interaction between digital skills and financial knowledge. Its coefficient is 0.0169 and is significant at the 1% level. The result indicates that simultaneous improvements in the two capabilities are associated with greater financial asset diversification, providing initial evidence consistent with capability complementarity.

Column (5) adds household-head and household characteristics, and column (6) further includes year and province fixed effects. In the preferred baseline specification, the coefficients on digital skills, financial knowledge, and their interaction are 0.0134, 0.0118, and 0.0167, respectively, all significant at the 1% level. The complementarity coefficient remains stable as controls and fixed effects are added, suggesting that the positive association is not fully explained by household characteristics, regional differences, or survey-year differences.

Overall, digital skills and financial knowledge are each positively associated with financial asset diversification among older households, and their interaction provides evidence consistent with capability complementarity. H1 is supported.

5. Endogeneity Discussion and Robustness Checks

5.1. Robustness Checks

Table 4 evaluates the robustness of the baseline result across year-specific estimates, controls for time-varying regional shocks, asset-balance thresholds, and alternative standardization. The interaction coefficient remains positive and statistically significant in both waves, after including province-by-year fixed effects, when the minimum balance is raised to CNY 1,000, and when the two capability indices are standardized separately by year. The main

result is therefore not sensitive to a specific year, fixed-effects structure, asset-balance threshold, or standardization method.

Table 4. Baseline robustness checks.

Variable	(1) Baseline	(2) 2019	(3) 2021	(4) Province × year fixed effects	(5) Minimum balance: CNY 1,000	(6) Year-specific standardization
Standardized digital skills	0.0134*** (0.0010)	0.0151*** (0.0013)	0.0101*** (0.0016)	0.0134*** (0.0010)	0.0137*** (0.0012)	0.0154*** (0.0010)
Standardized financial knowledge	0.0118*** (0.0010)	0.0142*** (0.0013)	0.0080*** (0.0016)	0.0120*** (0.0010)	0.0118*** (0.0011)	0.0228*** (0.0013)
Capability complementarity	0.0167*** (0.0011)	0.0170*** (0.0014)	0.0168*** (0.0017)	0.0165*** (0.0011)	0.0164*** (0.0012)	0.0175*** (0.0012)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	N/A	N/A	Included in interaction fixed effects	Yes	Yes
Province fixed effects	Yes	Yes	Yes	Included in interaction fixed effects	Yes	Yes
Observations	18,947	12,138	6,809	18,947	15,579	18,947
R ²	0.1987	0.1973	0.2060	0.2001	0.2020	0.1986

5.2. Extended Robustness Checks

Table 4A summarizes additional checks that are directly related to the study’s main argument. These specifications examine whether the direction and significance of the complementarity term change when asset classifications, sample structure, component measures of digital skills, and additional household constraints are varied.

Table 4A. Extended robustness checks: measurement, sample structure, and additional controls.

Dimension	Specification	Observations	Complementarity coefficient	SE
Asset classification	Five classes: gold and derivatives combined	18,947	0.0165***	0.0011
Asset classification	Four classes: gold and derivatives excluded	18,947	0.0166***	0.0011
Sample structure	Balanced panel: households observed in both waves	6,446	0.0191***	0.0020
Sample structure	Stable-head proxy: same gender and plausible age change	5,208	0.0191***	0.0021
Alternative construction	Raw-score product	18,947	0.0294***	0.0020
Digital-skills component	Third-party-payment-account adoption × financial knowledge	18,947	0.0138***	0.0011
Digital-skills component	Smartphone use × financial knowledge	18,947	0.0112***	0.0009
Additional control	Continuous risk attitude + missing-value indicator	18,947	0.0152***	0.0011
Additional control	Share of household members in poor health	18,947	0.0167***	0.0011

Table 4A shows that the complementarity term remains positive and significant when the asset classification is changed and when the model is estimated in the balanced panel and the stable-head proxy sample. When digital skills are decomposed into third-party-payment-account adoption and smartphone use, the interaction of each component with financial knowledge is also positive and significant. The main result remains stable after controlling for risk attitudes and household health burdens. The complementarity association is therefore not driven by a single indicator definition or a specific sample configuration.

As an additional diagnostic, the complementarity term is randomly permuted 500 times within survey-year-by-province cells, and the baseline specification is re-estimated in each iteration. Figure 1 shows that the placebo coefficients are concentrated around zero, whereas the observed complementarity coefficient lies clearly to the right of the placebo distribution. The baseline result is therefore unlikely to be driven by random variation.

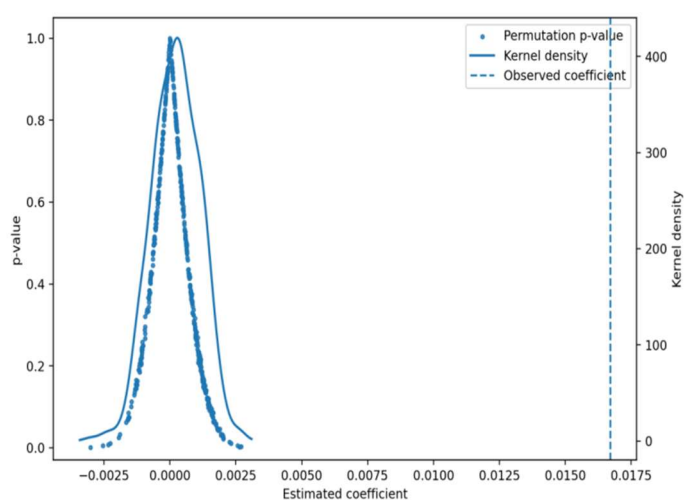


Figure 1. Permutation placebo test for the capability-complementarity coefficient.

5.3. Endogeneity and Sample-Selection Sensitivity

To address potential reverse causality and sample-selection concerns, the analysis considers temporal ordering and formal-financial-market participation. First, the 2019 capability measures are used to predict financial asset diversification in 2021. Column (2) of Table 5 shows that the complementarity term remains positive and significant after controlling for baseline household characteristics. Column (3) additionally includes 2019 PortfolioDiv to capture persistence in allocation habits and investment experience. Baseline diversification is strongly persistent, but the complementarity coefficient remains 0.0124 and significant at the 1% level. The baseline association is therefore not fully explained by contemporaneous reverse causality.

Second, sample selection may arise because portfolio weights and diversification can be computed only for households holding at least one included formal financial asset. Column (4) incorporates households outside the baseline sample into an expanded candidate sample. Column (5) further estimates entry probabilities using a Probit model and constructs inverse-probability weights. In both specifications, the complementarity term remains positive and close to the baseline estimate. Further diagnostics show that the maximum winsorized weight

is 1.7224 and that the maximum absolute standardized difference after weighting is 0.0073, indicating a well-behaved weight distribution and strong covariate balance. Overall, reverse-causality and sample-selection concerns do not alter the main findings.

Table 5. Endogeneity discussion and sample-selection sensitivity.

Variable	(1) Baseline	(2) Predict 2021: baseline characteristics	(3) Predict 2021: baseline diversification	(4) Expanded candidate sample	(5) Winsorized IPW
Standardized digital skills	0.0134*** (0.0010)	0.0135*** (0.0027)	0.0063** (0.0025)	0.0132*** (0.0009)	0.0135*** (0.0010)
Standardized financial knowledge	0.0118*** (0.0010)	0.0107*** (0.0025)	0.0051** (0.0022)	0.0121*** (0.0009)	0.0121*** (0.0010)
Capability complementarity	0.0167*** (0.0011)	0.0208*** (0.0027)	0.0124*** (0.0024)	0.0167*** (0.0011)	0.0167*** (0.0011)
Baseline PortfolioDiv			0.4324*** (0.0308)		
Controls	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes			Yes	Yes
Province fixed effects	Yes	Yes	Yes	Yes	Yes
Sample	Baseline	2019–2021 balanced panel	2019–2021 balanced panel	Expanded candidate sample	Baseline
Weights					IPW winsorized at 1%–99%
Observations	18,947	3,223	3,223	21,739	18,947
R ²	0.1987	0.2342	0.3694	0.1935	0.1971

6. Mechanism Analysis

Table 6. Capability profiles, portfolio scope, and probability-scale tests.

Capability profile	(1) Multi-asset portfolio Predicted probability	(2) Deposit-only allocation among participating households Predicted probability
Dual constraint	0.0472 (0.0022)	0.9438 (0.0025)
Knowledge advantage	0.0865 (0.0061)	0.9027 (0.0068)
Skills advantage	0.0986 (0.0035)	0.8864 (0.0040)
Dual enablement	0.1765 (0.0078)	0.8044 (0.0085)
Dual enablement – dual constraint	0.1293*** (0.0084)	–0.1394*** (0.0092)
Super additive increment	0.0386*** (0.0101)	–0.0409*** (0.0111)
Model	Probit	Probit
Controls	Yes	Yes
Year fixed effects	Yes	Yes
Province fixed effects	Yes	Yes
Sample	Expanded candidate sample	Households holding included assets
Observations	21,739	18,947

To identify the key margin through which digital-skills–financial-knowledge complementarity is associated with diversification, the analysis focuses on portfolio broadening. Whether households can move from single-asset holdings to multi-asset portfolios is an important manifestation of capability complementarity. Table 6 reports adjusted predicted probabilities of forming a multi-asset portfolio and of holding only cash and bank deposits under the four capability profiles.

6.1. *Capability Profiles and Portfolio Scope*

Column (1) of Table 6 shows that the predicted probabilities of forming a multi-asset portfolio are 4.72%, 8.65%, 9.86%, and 17.65% for dual-constraint, knowledge-advantage, skills-advantage, and dual-enablement households, respectively. The probability for dual-enablement households exceeds that for dual-constraint households by 12.93 percentage points, and the super additive increment is 3.86 percentage points. Column (2) shows that, among households holding included assets, the predicted probabilities of holding only cash and bank deposits are 94.38%, 90.27%, 88.64%, and 80.44%, respectively. The probability for dual-enablement households is 13.94 percentage points lower than that for dual-constraint households, with a super additive decline of 4.09 percentage points. The probability-scale evidence is consistent with capability complementarity.

6.2. *Key Margin of Capability Complementarity*

Table 6 indicates that the key margin of capability complementarity lies in reducing deposit-only concentration and helping households cross the threshold from single-asset holdings to multi-asset portfolios. Digital skills correspond to information acquisition and operational execution, whereas financial knowledge corresponds to product comprehension and risk judgment. Their combination is associated with broader holdings of formal financial assets. The mechanism interpretation is therefore deliberately limited to the expansion of portfolio scope rather than changes in the weight of any single asset class.

7. Further Analysis

The preceding results show that digital-skills–financial-knowledge complementarity is positively associated with diversification among older households. Its conversion into portfolio outcomes may nevertheless vary with internal preferences and the joint condition of rural residence and agricultural hukou status. Table 7 reports the corresponding heterogeneity analysis.

7.1. *Risk-Attitude Constraint*

Risk attitudes affect whether capability advantages translate into asset-allocation behavior. Column (1) of Table 7 shows that the complementarity association is 0.0178 among households willing to accept some risk. The interaction between high risk aversion and complementarity is -0.0108 , and the between-group difference is statistically significant. The implied complementarity association is therefore markedly weaker among highly risk-averse households. Risk preference constitutes an important boundary condition for the conversion of capabilities into diversified allocation.

7.2. Joint Rural-Residence–Agricultural-Hukou Constraint

The joint condition of rural residence and agricultural hukou status also shapes the conversion of capability advantages. Column (2) of Table 7 shows that the interaction between this condition and complementarity is significantly negative, with a statistically significant between-group difference. The complementarity association is therefore weaker among households residing in rural areas whose heads hold agricultural hukou status. Because this indicator captures a composite structural condition, the analysis does not attribute the difference to any single channel.

Table 7. Heterogeneity analysis: risk attitudes and the joint rural-residence–agricultural-hukou condition.

Variable	(1) Risk-attitude constraint	(2) Rural residence × agricultural hukou
Reference-group complementarity association	0.0178*** (0.0026)	0.0172*** (0.0014)
High risk aversion × complementarity	−0.0108*** (0.0028)	
Rural residence and agricultural hukou × complementarity		−0.0146*** (0.0018)
Reference group	Willing to accept some risk	Other households
Constrained group	Highly risk averse	Rural residence and agricultural hukou
Constrained-group complementarity association	0.0071	0.0026
p-value for between-group difference	0.0001	0.0000
Controls	Yes	Yes
Year fixed effects	Yes	Yes
Province fixed effects	Yes	Yes
Observations	15,003	18,947
R ²	0.2521	0.2093

8. Conclusions

Using the 2019 and 2021 waves of the CHFS, this study examines the associations between digital skills, financial knowledge, their complementarity, and financial asset diversification among older households. Digital skills and financial knowledge are each positively associated with diversification, and their interaction provides evidence consistent with capability complementarity. The key margin lies in reducing deposit-only concentration and helping households cross the threshold from single-asset holdings to multi-asset portfolios. Probability-scale tests further show that dual-enablement households are substantially more likely than dual-constraint households to form multi-asset portfolios and exhibit a significant super additive increment. Year-specific estimates, province-by-year fixed effects, alternative asset classifications, minimum-balance thresholds, temporal-prediction specifications, inverse-probability weighting, balanced-panel estimates, stable-head proxy samples, alternative constructions, and additional household controls all support the main findings. The complementarity association is stronger among households willing to accept some risk and weaker among households residing in rural areas whose heads hold agricultural hukou status.

The findings have several policy implications. First, digital-skills training and financial education should be integrated. Older adults should receive instruction not only on mobile-payment operations but also on basic concepts such as interest rates, inflation, and diversification. Second, age-friendly financial-service design should simplify operational procedures, strengthen risk warnings and suitability management, and retain necessary human-service channels to reduce the cost of using formal financial services. Third, investor education should be differentiated by risk attitudes. The objective should not be to maximize risky-asset exposure, but to help households form portfolios consistent with their retirement needs and risk-bearing capacity. Fourth, more targeted offline guidance, product explanations, and formal-financial-service support should be provided to older households residing in rural areas whose heads hold agricultural hukou status.

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Appendix A

The appendix reports robustness checks and diagnostic information not presented in full in the main text. Table 4A summarizes the results most closely related to the study’s main argument; the appendix provides the complete specifications. Unless otherwise stated, the models include household-head characteristics, household characteristics, year fixed effects, and province fixed effects, with standard errors clustered at the household level.

Table A1. Asset-classification and minimum-balance robustness checks.

Specification	Observations	Complementarity coefficient	SE
Six classes: province × year fixed effects	18,947	0.0165***	0.0011
Six classes: minimum balance of CNY 100	18,530	0.0165***	0.0011
Six classes: minimum balance of CNY 1,000	15,579	0.0164***	0.0012
Five classes: gold and derivatives combined	18,947	0.0165***	0.0011
Four classes: gold and derivatives excluded	18,947	0.0166***	0.0011
Seven classes: internet wealth management included	18,947	0.0181***	0.0011

Table A2. Balanced panel, stable-head proxy sample, and household-health-burden controls.

Specification	Observations	Complementarity coefficient	SE
Baseline regression	18,947	0.0167***	0.0011
Balanced panel: households observed in both waves	6,446	0.0191***	0.0020
Stable-head proxy: same gender and plausible age change	5,208	0.0191***	0.0021
Share of household members in poor health controlled	18,947	0.0167***	0.0011
Share of non-head household members in poor health controlled	18,940	0.0167***	0.0011
Health burden among co-resident non-head members controlled	18,942	0.0167***	0.0011

Table A3. Alternative constructions of the complementarity term.

Alternative construction	Observations	Coefficient	SE
Raw-score product	18,947	0.0294***	0.0020
Product after year-specific standardization	18,947	0.0175***	0.0012
Third-party-payment-account adoption × financial knowledge	18,947	0.0138***	0.0011
Smartphone use × financial knowledge	18,947	0.0112***	0.0009
Strict four-profile specification: knowledge advantage vs. dual constraint	18,947	0.0178***	0.0044
Strict four-profile specification: skills advantage vs. dual constraint	18,947	0.0301***	0.0025
Strict four-profile specification: dual enablement vs. dual constraint	18,947	0.1137***	0.0065

Table A4. Additional controls for risk attitudes.

Specification	Observations	Complementarity coefficient	SE
Baseline regression	18,947	0.0167***	0.0011
Continuous risk attitude + missing-value indicator	18,947	0.0152***	0.0011
Categorical controls for risk attitudes	18,947	0.0146***	0.0011

Table A5. IPW distribution and covariate-balance diagnostics.

Indicator	Winsorized		Interpretation
	Raw IPW	IPW (1%-99%)	
Mean	1.1470	1.1448	Overall weights are moderate
Median	1.1036	1.1036	Unchanged after winsorization
95th percentile	1.4240	1.4240	No marked tail inflation
99th percentile	1.7218	1.7218	Used as the upper winsorization threshold
Maximum	2.5524	1.7224	Winsorization reduces the influence of extreme weights
Maximum absolute standardized difference after weighting		0.0073	Well below 0.10

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