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Digital financial development and inefficient investment: a study based on the dual perspectives of resource and governance effects

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As one of the most crucial domains within the digital economy, digital finance has garnered significant attention due to its impact on firms. This study empirically examines the influence of digital finance on inefficient investment, using a sample of Chinese non-financial firms from 2011 to 2019. Results show that digital finance effectively mitigates firm inefficient investment, with a more pronounced effect observed in non-state firms and those operating in regions with higher levels of institutional development. Mechanism analysis demonstrates that digital finance mitigates inefficient investment through resource and governance effects. Further analysis shows that the breadth of coverage, use depth, and digital support services of digital finance all contribute to reducing inefficient investment. Moreover, digital finance enhances the willingness and ability of firms to invest and improves their overall investment levels. These results provide evidence for the positive impact of digital finance in mitigating inefficient investment.

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Introduction

In March 2022, the Chinese government proposed to actively expand effective investments, optimize investment structures, crack investment problems, and strive to improve the efficiency of firm investments. Investment activities are a pivotal aspect of firms, involving resource allocation to generate wealth for shareholders. Investment decisions and their outcomes determine a firm's future cash flow and profitability. Efficient investment also serves as the microfoundation of socio-economic growth. Investment efficiency refers to the extent to which a firm's actual investments deviate from the optimal level of investment[1]. In general, inefficient investment can manifest in two distinct forms: underinvestment behavior occurs when a firm lacks the necessary funds, has no excess capital for investment, or cannot bear the consequences of investment failure, leading to the abandonment of investment projects with positive net present value (NPV). Overinvestment behavior occurs when a firm has an abundance of funds and invest in projects with a negative NPV.

Existing studies on the factors influencing firm investment efficiency can be broadly categorized into two perspectives. The first perspective focuses on the influence of external formal and informal institutional factors in guiding and regulating firm investment behavior, specifically the role of policy environment (Yang et al., 2023; Zhou and Zhao, 2022), political resources (Boubakri et al. 2008), and regional institutional development (Kong et al., 2023) in mitigating inefficient investment. The second perspective emphasizes the significant role of either firm managers or shareholders in mitigating inefficient investment (Habib and Hasan, 2017) and explores paths for mitigating inefficient investment based on the upper echelons theory[2] and information asymmetry theory. Inefficient investment can severely hinder the achievement of firm strategic objectives and lead to a loss of social welfare.

These studies indicate that understanding a firm's inefficient investment requires consideration of financing constraints stemming from market imperfections, as well as information asymmetry and agency costs due to weak governance (Almeida and Campello, 2007; Chen et al., 2017). Digital finance, an emerging model in financial development, might provide such a solution. This merging model, at its core, merges digital technology with finance to serve all societal segments comprehensively and efficiently, with the initial intention of emphasizing the increased accessibility of financial services through the continuous improvement of financial infrastructure. Digital finance has the potential to transform and improve the efficiency of financial services and optimize the allocation of resources. However, its effect on inefficient investment still needs to be clarified. Can digital finance, with its attributes of inclusivity, convenience, and accessibility, influence inefficient investment through efficient financial supply, accurate user profiling, refined risk pricing, and intensive business processes (Demertzis et al., 2018)?

Theoretically, compared to traditional finance, digital finance expands the scope of financial services, eliminating spatial and temporal constraints (Gomber et al., 2017; Khan et al., 2018). This promotes decision-makers in accessing richer and more relevant information for investment decisions, thereby reducing firm financing constraints. A consistent and stable source of funding is especially crucial for firm investment efficiency. Furthermore, digital finance harnesses digital technology to mine vast amounts of standardized and non-standardized data. This reduces the high-risk premiums and operational costs associated with information asymmetry in traditional finance, ensuring a better match between resources and the risk characteristics of firm investment projects (Demertzis et al., 2018). Reduced information asymmetry of firms aids in optimizing resource allocation efficiency, mitigating firm inefficient investment. Finally, digital finance offers convenient channels for investor supervision and capital market regulation. Under the joint supervision of the market and government, the costs and risks of self-interested behaviors by managers and controlling shareholders significantly increase. This effectively mitigates the principal-agent problem, mitigating the firm inefficient investment (Erkan and Nguyen, 2021).

Based on the analysis above, this study examines the impact of digital finance on firm investment efficiency from the dual perspectives of resource and governance effects. The "resource effect" is the integration of finance and digital technology, enabling firms to access precise, convenient, and high-quality financial services, thereby gaining a resource advantage. The "governance effect" is mainly through integrating finance and digital technology to form an efficient and accurate monitoring of firms, reducing agency conflicts and information asymmetry between firms and external stakeholders. The results demonstrate that digital finance significantly mitigates inefficient investment of Chinese listed firms. This finding remains robust even after endogeneity tests and robustness tests. Mechanism analysis reveals that the mitigating effect is mainly through the resource and governance effects. Furthermore, the impact of digital finance on inefficient investment is more pronounced among non-state firms and firms operating in regions with higher levels of institutional development. The subdivision of the inefficient investment dimension finds that digital finance has a more pronounced mitigating effect on overinvestment. The subdivision of the digital finance dimension then shows that all three sub-dimensions contribute to mitigating inefficient investment. Additionally, digital finance significantly improves overall firm investment levels.

The three major contributions of this paper are as follows: First, we have expanded the literature concerning digital finance and its economic effects. Most existing studies have explored the impact of digital finance on household income, innovation, entrepreneurship, financialization, and risk-taking. Scholars have yet to examine how digital finance can mitigate firm inefficient investment from the dual perspectives of resource and governance effects. Second, our research broadens the study of the relationships between financing constraints, information asymmetry, agency costs, and inefficient investment. Other studies suggest that market imperfections leading to financing constraints, coupled with low governance levels resulting in information asymmetry and agency costs, contribute to inefficient investment (Huang et al., 2023; Almeida and Campello, 2007; Chen et al., 2017). Our empirical results indicate that digital finance effectively mitigates financing constraints, reduces information asymmetry and agency costs, and substantially diminishes inefficient investment. These findings enrich the research on the determinants of inefficient investment, highlighting the pivotal roles of resource and governance effects. This offers insights for guiding firms to optimize their investment structures and expand effective investments. Third, this study provides empirical evidence of the positive impact of digital finance on economic development. Governments should accelerate the construction of a digital financial service system, enhance the efficiency of financial services, and support firms in using digital finance as a tool to improve investment efficiency. Moreover, our research indicates that digital finance, as a novel governance model, can effectively address the deficiencies of corporate governance, illustrating a mutually reinforcing and complementary relationship between the two. This offers a theoretical reference for financial regulatory agencies to shape digital supervisory approaches.

Theoretical analysis and hypothesis

According to neoclassical theory, firms should execute all projects with a positive NPV and discard those with a negative NPV (Modigliani and Miller, 1958). However, due to imperfections in capital markets, firms often deviate from their optimal investment levels. Based on existing research, this study introduces the resource and governance effects as a theoretical framework to explore the impact of digital finance on inefficient investment.

The resource effect of digital finance affects inefficient investment. The efficiency of firm investment is contingent on their resource endowment. Digital finance enhances the efficiency of financial resource utilization, providing firms with "precise drip" financial services. China is still a bank-led financial supply system, making it difficult for long-tail groups to obtain financial services. Digital finance has stronger geographical penetration and lower costs, thus lowering the access threshold of the capital demand side, ultimately making it more convenient and affordable than traditional financial services.

Moreover, the "demand-supply" mismatch of traditional financial services becomes evident, while digital finance offers a broader array of high-quality financial products and services (Gomber et al., 2017). For example, China Construction Bank leverages 5G to support the remote processing of financial services and expand the scope of business services. This optimizes the allocation of financial assets and enhances firm financing opportunities. Furthermore, digital finance, harnessing the power of digital technology, quickly and effectively collects, transforms, and analyzes firms' financial status, business capacity, and credit rating. This enables financial institutions to establish customer credit systems and have a more precise judgment of firm credit status.

The governance effect of digital finance affects inefficient investment. According to agency theory, managers are often viewed as self-interested (Chen et al., 2017). Conflicts of interest between management and shareholders can lead managers to either take excessive risks and make significant investments without considering the cost–benefit principle or avoid risks and abandon positive NPV projects. Along with the first type of agency problem mentioned above, the dominance of a controlling shareholder can also increase the probability of moral hazard. Digital finance leverages digital technology to implement monitoring and incentives for controlling shareholders (Demertzis et al., 2018), reducing their equity pledge rates. Mitigating agency conflicts has a strong signaling and orientation function, enabling capital market investors to discern positive firm trajectories.

It is also generally believed that with the increase of information asymmetry comes the likewise increase in inefficient investment (Bushman and Smith, 2001). Information asymmetry introduces uncertainty into the returns on investment for outside investors, who may demand higher rates of return on the capital they provide (Stiglitz and Weiss, 1981). This increased financial pressure on firms can lead them to abandon investment projects that generate positive NPV, resulting in underinvestment. Information asymmetry can also hinder the effective allocation of interests between shareholders and managers, giving rise to moral hazards. Managers may formulate projects that do not maximize the firm's interests, potentially resulting in overinvestment.

However, digital technology can analyze vast amounts of data at relatively low costs and broaden access to information (Gomber et al., 2017). Specifically, the application of digital technology empowers financial institutions to gain insight into a firm's past operational conditions and transaction history, efficiently and accurately collect firm information, record the entire process of using firm investment funds, and efficiently monitor the potential risky utilization of funds and irregularities in the firm's investment process in real-time. These reduce the difficulty of collecting firm information from financial institutions.

Digital financial institutions employ digital technology to analyze executive behavior, the entire supply chain, and other relevant data, enabling them to measure firm performance and operating conditions objectively and accurately. The improved internal information environment can restrain the self-interested behavior of managers and promote the matching of firm resources with the risk characteristics of investment projects (Demertzis et al., 2018). The increased ability of financial institutions to identify pertinent information also encourages firms to disclose data more accurately (Kong et al., 2022). Therefore, the following hypothesis is proposed:

H1: Digital finance can significantly mitigate a firm inefficient investment.

Methods

Sample. The study's sample consists of non-financial industry-listed firms in Shanghai and Shenzhen A-shares, spanning the period from 2008 to 2019. Data preprocessing steps were as follows: (1) Firms with an asset-liability ratio >1 or <0 were excluded; (2) ST, * ST, and PT firms were also removed; (3) firms with missing data on key variables were subsequently excluded; and (4) continuous variables were winsorized at the 1 and 99% levels. Our final sample included 19,780 observations.

Main variables

Firm inefficient investment (INVEFF). Following Biddle et al. (2009), the following regression model was constructed to estimate inefficient investment:

$$\text{Invest}_{i,t} = \beta_0 + \beta_1 \text{SalesGrowt}_{i,t-1} + \varepsilon_{i,t} \quad (1)$$

In Model (1), $\text{Invest}_{i,t}$ represents the capital level, and $\text{SalesGrowt}_{i,t\text{-}1}$ represents the change in sales revenue from year $t-1$ to year t. The estimation of Model (1) is estimated by year and industry, and the absolute value of the regression residuals represents the firm inefficient investment. A higher absolute value indicates a more pronounced level of inefficient investment.

Digital finance (DWF). The Digital Inclusive Finance municipal-level index (2011–2019) was used to measure the level of digital finance in each region, which was divided by 100 to make the results more intuitive. This treatment does not affect the significance level. Provincial-level indicators were then selected in the robustness test.

The Digital Finance Index was jointly developed by Peking University's Institute of Digital Finance and Ant Financial Services Group, based on the digital financial data from Ant Financial. It measures digital finance from three dimensions: coverage breadth, use depth, and the digitization degree of inclusive finance (Guo et al., 2020). Coverage breadth refers to the number of electronic accounts in a province, such as the number of Internet payment accounts. Use depth pertains to the availability of digital financial services like payments, credit, insurance, and investments. The degree of digitalization of inclusive finance, covering mobile, affordable, creditable, and facilitate, is the embodiment of Internet technology (Huang et al., 2023).

Control variables. To avoid potential deviations in the empirical results arising from the omission of critical variables and follow

Table 1 Variable definitions.

Types	Name	Symbol	Definitions
Dependent variable	Inefficient investment	INVEFF	As mentioned earlier, the absolute value of the regression residuals
	Overinvestment	OVER	As mentioned earlier, the absolute value of residuals >0
	Underinvestment	UNDER	As mentioned earlier, the absolute value of residuals <0
Independent variable	Digital inclusive finance	DWF	Municipal-level Digital Financial Inclusion Index
Control variables	Firm size	Size	Natural logarithm of total assets at the end of the year
	Financial leverage	Lev	Total liabilities divided by total assets at the end of the year
	Firm performance	ROA	The ratio of net profits to the total assets
	Ownership concentration	Top1	Number of shares held by the largest shareholder divided by the total number of shares of the firm
	Board size	Board	The natural log of the number of directors on the board
	Number of firm four committees	Comnum	The number of audits, strategy, remuneration, and nomination committees established.
	State ownership	State	Take the value of one when a firm's ultimate controlling shareholder is government and 0 otherwise.
	Listing age	Age	The natural log of [listing years + 1]
	Cash ratio	Cash	The ratio of cash flow generated from the firm's operating activities to total assets
	Stock returns	Ret	Annual return on firm stock considering reinvestment of cash dividends
	Percentage of fixed assets	PPE	Firm fixed assets divided by total assets

Table 2 Descriptive statistics.

Variables	Obs.	Mean	Median	Std. dev.	Max	Min
INVEFF	19,780	0.039	0.030	0.039	0.229	0.001
OVER	6869	0.057	0.036	0.063	0.454	0.000
UNDER	12,911	0.031	0.029	0.020	0.148	0.000
DWF	19,780	2.069	2.184	0.661	3.086	0.545
Size	19,780	22.287	22.116	1.282	26.190	19.852
Lev	19,780	0.442	0.436	0.207	0.910	0.059
ROA	19,780	0.036	0.035	0.063	0.208	−0.253
Top1	19,780	0.343	0.322	0.149	0.743	0.085
Board	19,780	2.136	2.197	0.199	2.708	1.609
Comnum	19,780	3.877	4.000	0.407	4.000	0.000
State	19,780	0.381	0.000	0.486	1.000	0.000
Age	19,780	2.293	2.398	0.656	3.258	1.099
Cash	19,780	0.237	0.164	0.229	1.362	0.016
Ret	19,780	0.107	−0.003	0.495	2.091	−0.582
PPE	19,780	0.219	0.185	0.164	0.708	0.002

previous studies (Chen et al., 2011; Hu et al., 2019; Wu et al., 2022), this study mainly selected the factors influencing inefficient investment in terms of firm characteristics and governance factors. The specific variable definitions and descriptions are shown in Table 1.

Model. Equation (2) is expressed as follows to test the hypothesis:

$$INVEFF_{i,t} = \alpha_0 + \alpha_1 DWF_{i,t} + \sum Control_{i,t}\theta + \sum Industry + \sum Year + \varepsilon_{i,t} \quad (2)$$

INVEFF represents inefficient investment, DWF represents digital finance, Controls represents the control variables, and ϵ is the random error term. The hypothesis is supported if the coefficient of α_1 in Model (2) is significantly negative, indicating that digital finance mitigates inefficient investment. Our main analyses also controlled for the unobserved heterogeneities at the industry and year level by including industry and year-fixed effects.

Empirical analysis

Descriptive statistics. Results of the descriptive statistics of the main variables are shown in Table 2. The mean value of inefficient investment (INVEFF) is 0.039, with a standard deviation of 0.039, indicating a substantial variation in the level of inefficient investment. The mean overinvestment value (OVER) is 0.057, with a standard deviation of 0.063. The mean value of underinvestment (UNDER) is 0.031, with a standard deviation of 0.020. As for digital finance (DWF), the mean value is 2.069, and the standard deviation is 0.661. The values of other variables are reasonable, and no outliers are present.

Benchmark regression. Table 3 presents the impact of digital finance on inefficient investment. In Column (1), the coefficient of digital finance (DWF) is −0.005 and significant at the 1% level. In Column (2), the regression results show a negative and significant coefficient for digital finance (DWF) at the 5% level. The regression results of Column (3) demonstrate a negative and significant coefficient for digital finance (DWF) at the 1% level. The consistent results across Columns (1)–(3) indicate that digital finance significantly mitigates firm inefficient investment, providing support for H1. For the economic significance, when digital finance increases by one standard deviation, firm inefficient investment decreases by 8.47% (−0.005*0.661/0.039).

Endogeneity test

Heckman test. The Heckman two-stage model was employed to address the endogeneity issue. In the first stage, a dummy variable (DWF_A) was created based on whether the digital finance level of the firm's location exceeded the annual median; it was coded as 1 and 0 otherwise. The dummy variable was used as a dependent variable. Also, the proportion of other firms (excluding the focal firm) in the same industry with high digital finance levels (Other-DWF) was added as an exogenous instrumental variable to construct an inverse Mills ratio (IMR), which was added to the benchmark regression. As shown in Columns (2)–(4) of Table 4, the coefficients of IMR are all statistically significant at the 1% level. However, after controlling for sample selection bias, the regression coefficients for digital finance on inefficient investment, overinvestment, and underinvestment remain significantly negative. Results show that the conclusions remain valid even after considering the sample selection bias.

Instrumental variable. Following Liu et al. (2021), internet penetration by province (NET) was used as an instrumental variable. As shown in Table 5 of columns (1), (3), and (5), the coefficients of NET are all significant at the 1% level. In columns

Table 3 Benchmark regression.

Variables	(1) INVEFF	(2) OVER	(3) UNDER
DWF	−0.005*** (−2.610)	−0.011** (−2.356)	−0.004*** (−3.247)
Size	−0.001** (−2.147)	−0.000 (−0.297)	−0.003*** (−10.242)
Lev	0.020*** (8.577)	0.056*** (8.316)	0.004*** (2.645)
ROA	0.045*** (7.497)	0.131*** (7.107)	−0.019*** (−5.851)
Top1	0.003 (0.917)	0.005 (0.689)	0.005*** (2.666)
Board	−0.004** (−2.138)	−0.009* (−1.832)	−0.001 (−1.137)
Comnum	−0.000 (−0.295)	−0.002 (−0.683)	−0.000 (−0.133)
State	−0.004*** (−4.271)	−0.009*** (−3.268)	0.000 (0.008)
Age	−0.003*** (−4.077)	−0.009*** (−4.535)	0.005*** (11.918)
Cash	−0.004** (−2.473)	−0.012** (−2.335)	0.003*** (2.737)
Ret	0.003*** (4.509)	0.007*** (3.410)	−0.000 (−0.016)
PPE	0.017*** (4.267)	0.023*** (2.785)	−0.016*** (−6.916)
Constant	0.090*** (8.118)	0.115*** (4.113)	0.102*** (15.413)
Year FE	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes
Observations	19780	6869	12911
Adj.R^2	0.080	0.085	0.208

t value after clustering adjustment at the firm level is shown in brackets; *, **, and *** indicate significance at 10%, 5%, and 1%.

Table 4 Heckman test.

Variables	(1) Phase I DWF_A	(2) Phase II INVEFF	(3) Phase II OVER	(4) Phase II UNDER
DWF		−0.004** (−2.812)	−0.009* (−2.105)	−0.004*** (−4.327)
Other-DWF	−0.913*** (−3.062)			
IMR		−0.016*** (−6.304)	−0.032*** (−4.066)	−0.010*** (−6.777)
Controls	Yes	Yes	Yes	Yes
Constant	2.546*** (4.567)	0.085*** (8.410)	0.115*** (4.001)	0.098*** (18.176)
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Observations	12491	12491	4235	8256
Pseudo-R^2/Adj. R^2	0.458	0.074	0.092	0.182

t value after clustering adjustment at the firm level is shown in brackets; *, **, and *** indicate significance at 10%, 5% and 1%.

Table 5 IV test.

Variables	(1) Phase I DWF	(2) Phase II INVEFF	(3) Phase I DWF	(4) Phase II OVER	(5) Phase I DWF	(6) Phase II UNDER
DWF		−0.005* (−1.960)		−0.014* (−1.862)		−0.004*** (−2.651)
NET	0.009*** (94.892)		0.009*** (52.602)		0.009*** (78.621)	
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.343*** (11.802)	0.090*** (12.090)	0.235*** (4.521)	0.117*** (5.442)	0.405*** (11.282)	0.103*** (22.901)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	19780	19780	6869	6869	12911	12911
Adj. R^2	0.942	0.080	0.943	0.084	0.942	0.208

t value after clustering adjustment at the firm level is shown in brackets; * and *** indicate significance at 10% and 1%.

(2), (4), and (6), the coefficients of digital finance remain significantly negative, thereby further supporting H1.

Robustness tests

Replacement variable measurement. In this study, the indicator caliber for digital finance (DWF) previously used was replaced with the provincial-level indicator (PDWF). As shown in Table 6 of columns (1)–(3), the coefficients of digital finance (PDWF) at the provincial level are consistent with the previous study. For the dependent variable, following Richardson (2006), the growth rate of operating income was used to measure investment opportunities and calculate the inefficient investment of firms, denoted as INVEFF1, OVER1, and UNDER1. As demonstrated in Columns (4)–(6) of Table 6, the coefficients of digital finance remain largely consistent with the previous study, and the conclusions are robust.

Excluding the impact of municipalities directly under the Central Government. Considering Chinese municipalities' economic and policy peculiarities directly under the Central Government, the relationship between digital finance and inefficient investment may differ from other regions. Therefore, this study excluded the

Table 6 Replacement variable measurement.

Variables	(1) INVEFF	(2) OVER	(3) UNDER	(4) INVEFF1	(5) OVER1	(6) UNDER1
PDWF	−0.004*** (−4.465)	−0.010*** (−3.449)	−0.003*** (−4.382)			
DWF				−0.006** (−2.339)	−0.014** (−2.391)	−0.002* (−1.815)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.088*** (11.980)	0.110*** (5.198)	0.100*** (22.962)	0.082*** (5.278)	0.107*** (3.205)	0.108*** (12.061)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	19780	6869	12911	19780	7205	12575
Adj. R^2	0.077	0.077	0.204	0.059	0.094	0.100

t value after clustering adjustment at the firm level is shown in brackets; *, **, and *** indicate significance at 10%, 5% and 1%.

Table 7 Removal of some samples.

Variables	Excluding the impact of municipalities directly under the Central Government			Excluding GEM firms from the sample		
	(1) INVEFF	(2) OVER	(3) UNDER	(4) INVEFF	(5) OVER	(6) UNDER
DWF	−0.005** (−2.248)	−0.010* (−1.799)	−0.004*** (−3.410)	−0.005** (−4.622)	−0.012** (−3.709)	−0.003*** (−4.890)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.088*** (6.972)	0.115*** (3.663)	0.105*** (14.668)	0.093*** (11.733)	0.119*** (5.034)	0.101*** (21.170)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	15977	5742	10235	16678	5640	11038
Adj. R^2	0.071	0.074	0.199	0.083	0.078	0.219

t value after clustering adjustment at the firm level is shown in brackets; *, **, and *** indicate significance at 10%, 5% and 1%.

sample from the regression tests. The results in Columns (1)–(3) of Table 7 show that the coefficients for digital finance remain significant, at least at the 10% level, and the conclusions of this study are robust.

Excluding GEM firms from the sample. The presence of GEM-listed firms with low approval and threshold requirements, firms in a period of high growth and accompanied by higher risks, may impact the findings. The results of estimating the model by excluding GEM-listed firms are shown in Table 7. The results in Columns (4)–(6) demonstrate that the coefficients of digital finance remain significant, at least at the 5% level, affirming the robustness of the conclusions.

Consider the trend effect of the industry. Given that many industries were subject to fluctuations in the industry cycle during the study sample period, such as the coal and steel industries, and different industries are affected by different industrial macro policies each year, these factors could introduce bias in the analysis. We controlled the fixed effect of industry multiplied by year to eliminate the influence of various macroeconomic factors. As observed in the results presented in Table 8, the coefficients for digital finance remain significant, at least at the 5% level, indicating that the conclusions remain consistent after considering potential influences like industrial policies.

Mechanism analysis. As previously mentioned, this study explores the mechanisms of digital finance to mitigate inefficient investment from the perspectives of resource and governance effects. We test the resource effect from the perspective of financing constraints and the governance effect from the perspectives of agency costs and information asymmetry. In order to test whether these mechanisms hold, the following regression

Table 8 Consider the trend effect of the industry.

Variables	(1) INVEFF	(2) OVER	(3) UNDER
DWF	−0.005**	−0.010**	−0.004***
	(−2.460)	(−2.063)	(−3.079)
Controls	Yes	Yes	Yes
Constant	0.075***	0.079**	0.098***
	(5.450)	(1.967)	(10.710)
Year FE	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes
Year × Industry	Yes	Yes	Yes
Observations	19780	6869	12911
Adj. R^2	0.083	0.085	0.223

t value after clustering adjustment at the firm level is shown in brackets; ** and *** indicate significance at 5% and 1%.

model was constructed:

$$\begin{aligned} \mathrm{LNVEFF}_{i,t} = {} & \alpha_0 + \alpha_1 \mathrm{Constr}_{i,t} + \alpha_2 \mathrm{Constr}_{i,t} {}^{*} \mathrm{DWF}_{i,t} \\ & + \sum \mathrm{Control}_{i,t}\theta + \sum \mathrm{Industry} + \sum \mathrm{Year} + \varepsilon_{i,t} \end{aligned} \quad (3)$$

where $\mathrm{Constr}_{I,t}$ represents the financing constraints, tests for agency costs ($\mathrm{Agency}_{i,t}$) and information transparency ($\mathrm{Trans}_{i,t}$) are similar to the financing constraints. As seen from the results in Table 9, following Kaplan and Zingales (1997), the KZ index was used to measure financing constraints, with a larger value indicating a more severe constraint faced by the firm. From the regression results in Column (1), financing constraints are positively related to underinvestment, and the coefficient of the interaction terms (KZ*DWF) is significantly negative at the 1% level. Therefore, digital finance effectively mitigates the underinvestment resulting from financing constraints.

Following Ang et al. (2000), the management expense ratio was used to measure agency costs, with larger values indicating higher agency costs. The results are presented in Column (2). The

Table 9 Mechanism analysis.

Variables	(1) UNDER	(2) INVEFF	(3) INVEFF
KZ*DWF	−0.000***		
	(−2.655)		
KZ	0.002*** (5.177)		
Agency*DWF		−0.014**	
		(−2.079)	
Agency		0.054***	
		(3.644)	
Trans*DWF			0.006** (2.279)
Trans			−0.025***
			(−3.904)
Controls	Yes	Yes	Yes
Constant	0.089***	0.077***	0.093***
	(13.351)	(6.617)	(8.095)
Year FE	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes
Observations	12602	19780	19780
Adj. R^2	0.213	0.082	0.082

t value after clustering adjustment at the firm level is shown in brackets; *, **, and *** indicate significance at 5% and 1%.

analysis shows a positive relationship between agency costs and inefficient investment, and the coefficient of the interaction terms (Agency*DWF) is significantly negative at the 5% level. Therefore, digital finance effectively mitigates inefficient investment resulting from agency costs.

Following Liu et al. (2023), stock price synchronicity was used to measure information transparency, with higher values indicating higher information transparency. The results in Column (3) indicate a significant negative relationship between information transparency and inefficient investment, with the coefficient of the interaction terms (Trans*DWF) being significantly positive at the 5% level. Therefore, digital finance effectively mitigates inefficient investment stemming from information asymmetry.

Heterogeneity analysis

Regional institutional development. Firms are embedded in specific social environments, and managers make strategic decisions within the established institutional framework. Regarding the resource effect mechanism, investment activities' inherent uncertainty and longer cash flow feedback render investment returns uncertain. In regions with lower levels of institutional development, the quality of policy implementation tends to be lower, and government commitment to policies may be less credible. Consequently, firms in such regions tend to adopt a more cautious approach to their investment behavior. In terms of governance effect mechanism, a low level of institutional development exacerbates the challenge of monitoring managers (Xiong et al., 2023), thus leaving room for opportunistic behavior. In addition, a low level of institutional development implies an increase in external risk, thereby weakening the quality of firm information and influencing managerial judgment and investment decisions (Stulz, 1996). In summary, we infer that the resource and governance effects of digital finance are most effective in regions with higher levels of institutional development, resulting in a more pronounced mitigation effect.

Accordingly, the study used the marketization index of the region to measure institutional development. When the institutional development of the firm location exceeded the annual median, it was categorized as the higher-level institutional development group. Otherwise, it was categorized as the lower-level institutional development group. From the regression results in columns (1) and (2) of Table 10, the coefficient on digital finance is insignificant in the group with lower levels of institutional development. However, in the group with higher levels of institutional development, the coefficient of digital finance is −0.009 and significant at the 1% level. The test of difference between these two groups is significant at the 5% level, clearly indicating that the mitigation effect is more pronounced in regions with higher levels of institutional development.

Nature of firm. Given the unique characteristics of the Chinese institutional context, it is necessary to further distinguish the impact of property rights when examining the relationship between digital finance and firm inefficient investment. In terms of resource effect mechanism, state-owned firms find it comparatively easier to secure financial institution resources for their investment projects than non-state-owned firms, which rely more on market competition to obtain funds, making securing external funds a more challenging process. The original intention of digital finance is to expand the coverage of financial services, provide diversified financial services, and connect millions of users while the cost of adding one more user at the margin is nearly zero, thereby generating the long-tail effect.

Regarding the governance effect mechanism, the characteristics of non-state-owned firms weaken the constraints on controlling shareholders, and credit sector institutions consider compensating their risky returns through higher risk premiums when they cannot judge whether funds will be appropriated. The Chinese government has recently further strengthened the regulation of state-owned firms, and the self-interested risk aversion and blind risk appetite of state-owned firm managers have been restrained. State-owned firms are subject to stricter external stakeholder monitoring (Jiang et al., 2010). In addition, information asymmetry between financial institutions and non-state-owned firms also constrains the financing of non-state-owned firms, such as challenges in assessing the development prospects and entrepreneurial talent of non-state-owned firms. In summary, this study argues that the resource and governance effects of digital finance have a more pronounced impact on non-state-owned firms.

Based on the regression results in Columns (3) and (4) of Table 10, the coefficient of digital finance is −0.007 and significantly negative at the 1% level in the group of non-state-owned firms. However, it is found insignificant in the group of state-owned firms. The difference test between these two groups is significant at the 5% level, underlining the more pronounced mitigating effect in the group of non-state-owned firms.

The impact of digital finance on different types of inefficient investment. The residual value of Model (1) represents the degree of inefficient investment, and we further distinguish them into underinvestment and overinvestment. This leads us to the question: What is the impact of digital finance on overinvestment and underinvestment, respectively? From the results in Column (1) of Table 11, the regression coefficient of digital finance is negative and significant at the 1% level. In Column (2) of Table 11, the regression coefficient of digital finance remains negative and significant at the 1% level, indicating its role in mitigating underinvestment. The test of difference between these two groups is significant at the 10% level, indicating the more pronounced effect of digital finance on overinvestment.

Heterogeneous impact of different dimensions of digital finance. This study further analyzes how the three sub-dimensions of digital finance impact inefficient investment. It aims to determine whether the effect of digital finance on inefficient investment is attributed to the broad range of digital financial services, the

Table 10 Heterogeneity analysis.

Variables	(1) Low	(2) High	(3) Non-state-owned	(4) State-owned
DWF	−0.001 (−0.107)	−0.009*** (−3.524)	−0.007*** (−3.431)	−0.001 (−0.550)
Controls	Yes	Yes	Yes	Yes
Constant	0.091*** (8.181)	0.089*** (8.809)	0.073*** (7.022)	0.088*** (8.849)
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Observations	8526	11254	12243	7537
Adj. R^2	0.075	0.084	0.076	0.096
Differences between groups	5.23**		4.47**	

t value after clustering adjustment at the firm level is shown in brackets; ** and *** indicate significance at 5% and 1%.

Table 11 The impact of digital finance on different types of inefficient investment.

Variables	(1) OVER	(2) UNDER
DWF	−0.011*** (−2.824)	−0.004*** (−4.492)
Controls	Yes	Yes
Constant	0.115*** (5.743)	0.102*** (24.281)
Year FE	Yes	Yes
Industry FE	Yes	Yes
Observations	6869	12,911
Adj. R^2	0.076	0.204
Differences between groups	3.82*	

t value after clustering adjustment at the firm level is shown in brackets; * and *** indicate significance at 10% and 1%.

Table 12 Heterogeneous impact of different dimensions of digital finance.

Variables	(1) INVEFF	(2) INVEFF	(3) INVEFF
COVER	−0.002** (−2.321)		
USAGE		−0.006*** (−5.649)	
DIGIT			−0.003** (−1.970)
Controls	Yes	Yes	Yes
Constant	0.089*** (12.034)	0.091*** (12.308)	0.088*** (11.955)
Year FE	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes
Observations	19,780	19,780	19,780
Adj. R^2	0.076	0.077	0.076

t value after clustering adjustment at the firm level is shown in brackets; ** and *** indicate significance at 5% and 1%.

Table 13 The impact of digital finance on the investment level of firms.

Variables	(1) INV_t	(2) INV_{t+1}	(3) INV_{t+2}
DWF	0.316*** (3.567)	0.314*** (3.070)	0.359*** (3.092)
Controls	Yes	Yes	Yes
Constant	−7.086*** (−14.834)	−6.809*** (−12.387)	−6.051*** (−9.603)
Year FE	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes
Observations	19,780	15,901	13,209
Adj. R^2	0.643	0.602	0.561

t value after clustering adjustment at the firm level is shown in brackets; *** indicate significance at 1%.

variety of types of digital financial services, or the convenience and low cost of digital finance. As shown in the regression results of Table 12, the breadth of coverage (COVER), use depth (USAGE), and the digitization degree of inclusive finance (DIGIT) all contribute to the mitigation of firm inefficient investment. Specifically, the breadth of digital financial coverage makes financial resources unrestricted by geography, providing firms with maximum access to financial services. The use depth indicates the availability of multiple financial functions for firms. Finally, the digitization degree of inclusive finance indicates that digital financial services are more convenient, less costly, and more efficient for firms.

The impact of digital finance on the investment level of firms. Digital finance mitigates inefficient investment of firms through both resource and governance effects. On the one hand, digital finance mitigates resource constraints and enhances firms' investment capabilities. On the other hand, digital finance reduces agency costs, improves information transparency of firms, and enhances firms' willingness to invest. Based on this, it can be inferred that digital finance also plays a role in improving the overall investment levels of firms. The firms' investment level (INV) was measured using the logarithm of the net cash spent on purchasing and constructing fixed assets, intangible assets, and other long-term assets in the current period, the next period, and the subsequent two periods. From the regression results presented in Table 13, the coefficients of digital finance are all positive and significant at the 1% level. These results indicate that digital finance not only mitigates inefficient investment but also contributes to the enhancement of the overall investment levels of firms.

Discussion and conclusions

This study examines the effect of digital finance on inefficient investment of firms, and the findings demonstrate that digital finance significantly mitigates inefficient investment. Subdividing the dimension of inefficient investment shows that digital finance effectively reduces both overinvestment and underinvestment, with a more pronounced impact on overinvestment. Mechanism analysis reveals that digital finance plays a pivotal role in mitigating underinvestment stemming from financing constraints, as well as inefficient investment due to agency costs and information asymmetry. Heterogeneity analysis indicates that this mitigation effect is more obvious in regions with higher levels of institutional development and for non-state-owned firms. Moreover, all three sub-dimensions of digital finance contribute to mitigating

inefficient investment, and digital finance also enhances the overall investment levels of firms.

The policy implications are as follows: First, digital finance has been shown to effectively mitigate inefficient investment of firms, providing strong evidence for improving firm investment efficiency. It is imperative for firms to proactively embrace the current trend of digital economic development, reduce any irrational investments, and leverage digital technology to empower their development. Second, this study revealed that all three dimensions of digital finance contribute to mitigating inefficient investment. Government departments should promote integrating digital technology and financial services more extensively and deeply. Third, government departments should focus on refining digital finance policies and regulations, forming long-term, transparent, sustainable, and benign interactions between firms and the government, and escorting digital finance to serve the real economy better.

Data availability

The datasets analyzed during the current study are available from the corresponding author upon reasonable request.

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Notes

1 In a perfect market, any project with a positive NPV should be invested in, and the most efficient investment should occur when a firm's marginal revenue equals its marginal cost (Modigliani and Miller, 1958). According to the empirical measurements in the Model (1) of this study, the regression residual represents the disparity between the actual amount of investment and the desired amount of investment. A value >0 indicates overinvestment, a value <0 indicates underinvestment, and when a firm's investment is at the most efficient level in the ideal state, the residual is 0.

2 Hambrick and Mason (1984) proposed the upper echelons theory from the information processing perspective. The theory contains three main perspectives: first, top managers base their decisions and strategic choices on their experiences and values, exerting a significant influence on organizational outcomes; second, the characteristics of the top management team are more predictive of organizational outcomes than those of individual top managers; and finally, demographic variables are meaningful.

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Author contributions

LX designed the study. LX and SJ collected the data. LX and JD performed most of the data analysis. SJ coordinated and supervised the study. LX and JD drafted the manuscript. All authors substantially contributed to the article and approved the submitted version.

Competing interests

The authors declare no competing interests.

Ethical approval

Not applicable as this study did not involve human participants.

Informed consent

This article does not contain any studies with human participants performed by any of the authors.

Additional information

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