How Digital Transformation in Commercial Banks Shapes Corporate Investment Decisions: Evidence from Chinese Listed Firms

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Citation: F. F. Ma, L. L. Dong, S. Fahad, and Y. Q. Cui, "How digital transformation in commercial banks shapes corporate investment decisions: Evidence from Chinese listed firms," *J. Intell Manag. Decis.*, vol. 5, no. 1, pp. 35–46, 2026. https://doi.org/10.56578/jimd050103.

Abstract: The digital transformation of commercial banks (DTCB) has altered the way financial institutions collect, process, and use information, with potential implications for firms' investment behaviour. This study examines whether and how DTCB affects corporate investment efficiency using panel data on Chinese listed companies from 2013 to 2023. The results indicate that a higher level of DTCB is associated with a statistically significant improvement in corporate investment efficiency. Further analysis suggests that this effect operates primarily through two channels: a reduction in financing constraints and a decline in agency costs. The heterogeneity analysis shows that the positive effect of DTCB on investment efficiency is concentrated among privately owned firms, while no significant effect is observed for state-owned enterprises (SOEs). These findings provide evidence that the DTCB reshapes firms' financing and governance environments in ways that influence investment outcomes. The study contributes to the literature on digital finance and corporate investment by offering firm-level empirical evidence on the economic consequences of banking digitalisation.

Keywords: Digital transformation of commercial banks; Corporate investment efficiency; Financing constraints; Agency costs; Investment decisions

1 Introduction

Currently, corporate investment efficiency in China remains relatively low. One prominent manifestation of this problem is that many enterprises are unable to exploit profitable investment opportunities because of limited access to external finance. The underdevelopment and structural imbalance of the financial system constitute an important reason for this inefficiency. When firms face valuable investment opportunities but lack sufficient internal funds, they require continuous and stable external financing. However, China's financial system has not yet reached a level of maturity that ensures an even and efficient allocation of financial resources, which constrains firms' ability to translate investment opportunities into actual capital formation. Commercial banks dominate China's financial system, yet their resource allocation remains imperfect. In practice, banks tend to favour large state-owned enterprises (SOEs) in credit provision, while small and medium-sized enterprises (SMEs) face severe credit constraints [1]. As a result, even highly productive SMEs may be unable to undertake value-creating investments because they cannot obtain sufficient financing [2]. These structural features of the financial system therefore contribute directly to persistent investment inefficiency among firms.

An efficient financial system can improve corporate investment efficiency by identifying firms with strong growth potential and allocating credit resources accordingly. Although China has made substantial efforts in recent years to foster the development of financial markets, commercial banks continue to play a dominant role in financing the real economy. According to data published by the People's Bank of China, the stock of social financing reached 378.09 trillion yuan in 2023, of which commercial bank loans accounted for 237.59 trillion yuan, representing 62.84% of total financing. This clearly indicates that commercial banks remain the primary providers of external funds to enterprises. Consequently, the functioning and evolution of commercial banks are of central importance for understanding changes in corporate investment behaviour and efficiency.

In this context, the ongoing digital transformation of commercial banks (DTCB) offers a potentially important channel for improving corporate investment efficiency. The DTCB involves the adoption and integration of digital technologies such as big data, artificial intelligence, cloud computing, the Internet of Things, and blockchain to develop new business models, redesign operational processes, and upgrade financial products and services. In recent years, commercial banks have increasingly accelerated this transformation process. Large banks, in particular, have established fintech subsidiaries and entered a stage of comprehensive digitalisation, reflected in the expansion of online platforms, intelligent service systems, and data-driven risk management tools. Through these changes, DTCB enhances banks' information collection and processing capabilities, reduces transaction and monitoring costs, improves risk assessment and control, and expands the effective supply of financial services. These transformations have the potential to alter the financing environment and governance conditions faced by firms, and thereby influence their investment behaviour and efficiency. Existing studies have documented that DTCB is associated with improvements in bank profitability, operational efficiency, risk management capacity, and the scale and structure of credit supply. Building on this literature, an important question remains insufficiently explored: if DTCB improves banks' capacity to supply and manage credit, does it also improve corporate investment efficiency? If so, through which mechanisms does this effect operate? Furthermore, does the impact of DTCB differ across firms with different ownership structures and institutional characteristics?

Despite the growing body of research on banking digitalisation, important gaps remain. Much of the existing literature focuses on how DTCB affects the volume and structure of corporate credit, while relatively little attention has been paid to its implications for the efficiency of firms' investment decisions. Targeted empirical evidence on the link between DTCB and corporate investment efficiency is still scarce. A systematic examination of this relationship is therefore necessary, both to extend existing theoretical insights and to provide a more complete understanding of the economic consequences of banking digitalisation.

Against this background, this study focuses on three main research questions. First, does DTCB significantly improve corporate investment efficiency? Second, through which mechanisms does DTCB influence investment efficiency, in particular with respect to financing constraints and agency costs? Third, does the effect of DTCB exhibit heterogeneity across different types of enterprises, especially between privately owned firms and SOEs? Addressing these questions is important not only for academic research, but also for policy discussions concerning financial reform, digital transformation, and resource allocation efficiency.

To address these issues, this study uses panel data on Chinese listed firms from 2013 to 2023 to examine the impact of DTCB on corporate investment efficiency. The empirical results indicate that DTCB is associated with a statistically significant improvement in corporate investment efficiency. Further analysis suggests that this effect operates primarily through the easing of financing constraints and the reduction of agency costs. In addition, the positive impact of DTCB is found to be concentrated among privately owned enterprises, while no significant effect is observed for SOEs.

This study makes several contributions. First, it extends the literature on digital transformation by shifting the focus from financial institutions in general to the specific role of commercial banks, thereby providing a more precise analytical perspective. Second, it enriches research on the economic consequences of DTCB by examining its implications for corporate investment efficiency. Third, it clarifies the channels through which DTCB affects investment efficiency by explicitly analysing financing support mechanisms and debt governance mechanisms.

The remainder of the paper is organised as follows. Section 2 reviews the relevant literature and develops the research hypotheses. Section 3 describes the data, variables, and empirical methodology. Section 4 presents and discusses the empirical results. Section 5 concludes and discusses the policy implications and limitations of the study.

2 Literature Review and Research Hypotheses

2.1 DTCB and Corporate Investment Efficiency

Commercial banks strengthen their role in financing support and debt governance for enterprises through the application of digital technologies, thus improving corporate investment efficiency. As a result, this research focuses on the impact of DTCB on the effectiveness of business investments from the perspectives of financing assistance and debt management.

(1) Analysis of financing support mechanism

The financial constraint is an important reason leading to inefficient investment. The Modigliani–Miller theorem assumes that there is no information asymmetry in the capital market, and enterprises do not face financing constraints [3]. In this case, managers allocate capital based on the objective of maximizing enterprise value, thereby automatically achieving the optimal capital allocation. The current Chinese market ranked third after the USA and Japan in terms of capitalization. However, it is mainly large companies that have access to financing in the capital market. For SMEs, it is difficult for them to meet their investment needs through internal financing, which makes them very dependent on external financing [4]. Since most enterprises find it difficult to obtain financing in

the equity and bond markets, enterprises primarily obtain financing from commercial banks. However, the existence of information asymmetry makes enterprises need to pay high costs to obtain loans and face serious financing constraints. Under the high financing constraint environment, enterprises have to reduce investment projects with relatively high risks and long investment cycles but higher returns [5], thus reducing investment efficiency.

The financing support function of commercial banks can improve corporate investment efficiency by providing loans to enterprises with good investment opportunities, to avoid the failure of such enterprises to grasp investment opportunities due to a lack of funds. The most outstanding performance of enterprises with better investment opportunities is their strong profitability. Therefore, this requires commercial banks to search for highly profitable enterprises and provide credit to them. Commercial banks have cost and professional advantages in collecting corporate information and evaluating corporate profitability, and they can select enterprises with high profitability [6]. Compared to individual investors, commercial banks can employ professionals to assess the credit risk of enterprises, collect and process enterprise-related information, and select enterprises with high profitability from numerous enterprises [7]. In addition, commercial banks increase the credit availability of highly profitable enterprises by playing the signal release function. Since commercial banks can supervise the actual operation of enterprises relatively effectively, it is a signal that enterprises can obtain loans from commercial banks, which is conducive for enterprises to raise more funds through equity or bonds [8].

Commercial banks' enhanced capacity to investigate business prospects reflects digitalization, thus improving investment efficiency. Digital technology enables commercial banks to expand information sources, improve the accuracy of information obtained, and obtain corporate information that cannot be obtained through traditional means [9]. By using digital technology, commercial banks are able to more efficiently integrate data platforms, such as those for e-commerce, social networks, and credit investigation, as well as extend the information sources accessible to businesses [10]. Commercial banks can fully mine data information such as entrepreneurs' social interaction, executives' academic experience, and industry and regional environment, and transform these data into useful information for credit issuing personnel to make decisions. Meanwhile, digital technology provides support to commercial banks in processing information [11]. By utilizing big data, cloud computing, blockchain technology, and statistical models, commercial banks have a stronger and quicker information processing capability as compared to the conventional method of artificial information processing [12]. Commercial banks can identify businesses with high profitability more effectively because of increased access to a wider variety of information sources and improved technology for processing information. This enables highly profitable enterprises that have been excluded in the past to obtain credit support [13].

(2) Debt governance mechanism analysis

The principal-agent problem is an important cause of inefficient investment. High efficiency of enterprise investment means that enterprises allocate capital to investment projects that can increase enterprise value the most, for example, allocating capital to technical assets that can improve enterprise productivity [14]. Two types of principal-agent problems affect an enterprise's investment behavior. The first type refers to the principal-agent problem between the owner and the manager of the firm. According to the 'free cash flow hypothesis', the managers and owners of an enterprise have different goals when they are separated. The goal of the owners is to maximize the enterprise value, while the goals of the managers are to focus on short-term performance and on-the-job consumption, which makes it difficult to allocate capital to projects that can improve the enterprise value in the long run. Therefore, the first kind of principal-agent problem reduces corporate investment efficiency. The second type refers to the principal-agent problem between major shareholders and minority shareholders. Highly concentrated ownership in China leads to a serious problem of interest encroachment by major shareholders on minority shareholders [15]. When the major shareholders control the enterprise, they tend to invest in fixed assets and professional assets. The purchase of such assets is convenient for the large shareholders to seize the interests of minority shareholders by means of asset transfer and internal transaction, which will crowd out the investment in technical assets of enterprises [16] and hinder enterprises from enhancing investment efficiency. In contrast, in the absence of a principal-agent problem, the enterprise capital will be allocated to the project that can increase the enterprise value the most. In the case of principal-agent problems, managers' shortsighted goals and more emphasis on nontechnical investment make it difficult to allocate capital to projects that can increase the value of the enterprise the most, resulting in inefficient investment in enterprises.

The debt governance function of commercial banks is helpful to alleviate the two kinds of principal-agent problems, thus improving corporate investment efficiency. For the first type of principal-agent problem, the loans provided by commercial banks to enterprises require the enterprises to repay the principal and interest, which reduces the discretionary cash flow of the management and the self-absorbed behaviors of the management [17]. For the second type of principal-agent problem, commercial banks can refuse to provide loans to major shareholders or raise loan interest rates to punish major shareholders' encroachment behavior. This is because commercial banks often provide loans not only to enterprises, but also to major shareholders of enterprises.

Commercial banks strengthen their role in the debt governance of enterprises through the application of digital

technologies, thus improving corporate investment efficiency. On the one hand, commercial banks obtain enterprise-related information in a more real-time manner by applying digital technology, which improves the supervisory ability of managers and strengthens debt governance [18]. Under stronger supervision, managers will act according to the principle of maximizing enterprise value, and funds will be allocated to the most value-adding projects [19]. On the other hand, DTCB is conducive to credit expansion, which increases commercial banks' risk-taking and encourages them to strengthen their connection with enterprises. In this case, commercial banks make more efforts to supervise the use of funds and operating behaviors of enterprises, thus strengthening the debt governance ability of enterprises. Based on the above discussion, the following hypotheses are formulated.

Hypothesis 1: DTCB can enhance corporate investment efficiency.

Hypothesis 2: DTCB can enhance corporate investment efficiency through easing corporate financing constraints.

Hypothesis 3: DTCB can enhance corporate investment efficiency by reducing corporate agency costs.

2.2 Ownership Heterogeneity

There is 'ownership discrimination' in the credit market of China, which is demonstrated by the fact that SOEs easily obtain loans from banks, while private enterprises face credit rationing. It is easy for SOEs to borrow from commercial banks due to their implicit government guarantee. However, the lack of collateral and information transparency makes it difficult for private enterprises to borrow from commercial banks [20]. For private enterprises, the DTCB improves their information search and processing capabilities, which allows more highly profitable enterprises to be identified by commercial banks. So, DTCB increases lending to highly profitable enterprises. DTCB mainly improves corporate investment efficiency by increasing loans to enterprises. On the one hand, the increase in commercial banks' lending to highly profitable enterprises avoids the underinvestment of these companies due to the lack of funds. On the other hand, the DTCB increases its ability to supervise enterprises that obtain loans and reduces the agency costs of these companies, thus improving investment efficiency. Therefore, DTCB increases lending to private firms, which improves corporate investment efficiency by alleviating financing constraints and reducing agency costs. For SOEs, it is easy to obtain loans before DTCB. Therefore, DTCB does not significantly increase lending to SOEs. Since DTCB improves investment efficiency by increasing lending to enterprises. Therefore, DTCB does not significantly affect SOEs' investment efficiency.

In conclusion, since private enterprises face credit rationing in the traditional credit market, DTCB increases lending to private enterprises, thus significantly improving private enterprises' investment efficiency. However, SOEs have easy access to loans before DTCB, so DTCB cannot increase lending to SOEs and thus has no significant effect on SOEs' investment efficiency. Therefore, we propose the following hypothesis.

Hypothesis 4: DTCB significantly improves private enterprises' investment efficiency, but cannot enhance SOEs' investment efficiency.

As illustrated in Figure 1, the mechanism of how DTCB affects corporate investment efficiency is summarized.
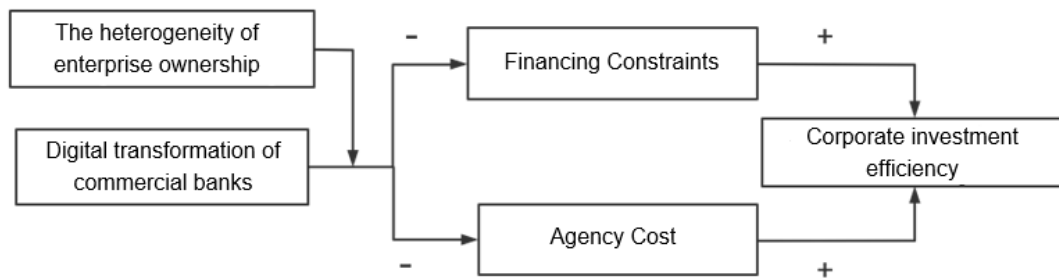

Figure 1. Mechanism of DTCB affecting enterprise investment efficiency

3 Methodology

3.1 Data and Sample Selection

The research sample of this study is the data of enterprises from 2013 to 2023. The data come from the CSMAR database. All variables are winsorized at 1%. Finally, an unbalanced panel data set is obtained, which comprises a total of 14,512 year-company observations.

3.2 Variable Definitions

(1) Dependent variable

Current investment level of enterprises (hereinafter referred to as "Ci"). Use the logarithm of the company's investment in the current period to measure. The following formula is used to calculate the current investment of the enterprise: Current investment = (capital expenditure - depreciation - income from the sale of long-term assets + acquisition of expenditure)/total assets.

(2) Explanatory variable

DTCB at the Enterprise Level (hereinafter referred to as "DTCBE") is measured at the business enterprise level. The foundational data for this indicator is derived from the China Commercial Bank Digital Transformation Index, compiled by the Institute of Digital Finance at Peking University. In the calculation process, the index scores of each bank that provided financing to the enterprise are first obtained. These scores are then weighted according to the proportion of the enterprise's total loans obtained from each bank during the given year, ultimately yielding the enterprise-level DTCBE value.

(3) Mediating variable

The theoretical analysis of this study shows that DTCB can improve enterprise investment efficiency through alleviating financing constraints and reducing agency costs. Therefore, this paper selects financing constraints and agency costs as mediating variables. Referring to existing research, the SA Index proposed by Hadlock and Pierce [21] is adopted to measure financing constraints. This paper uses the ratio of administrative expenses to operating revenue to measure agency costs. This indicator is widely used to measure agency costs in the current corporate governance literature. Administrative expenses are controlled by managers and can be used to evaluate spending beyond budget [22]. A higher level of this indicator means that the agency costs are greater. Therefore, this indicator reflects the waste caused by managers due to excessive on-the-job spending.

(4) Control variables

A set of control variables is included to capture key firm characteristics and other factors that may influence investment behaviour and performance. Table 1 summarises the control variables and their definitions.

Table 1. Variable definitions

Variables	Index.		Definition
Dependent variable	C_i	Current investment	The logarithm of the current investment.
Explanatory variable	DTCBE	DTCBE	The DTCB level of commercial bank that lend to enterprises.
	ROA	Return on assets	Net income divided by total assets.
Mediating variable	Ac	Agency cost	The ratio of administrative expenses to operating revenue.
	Fc	Financing constraints	The SA Index proposed by Hadlock and Pierce [21].
	Ca	Company age	The logarithm of company's age.
	Cs	Company size	The logarithm of company's number of employees.
	Soe	State-owned enterprise	1 if it's a Soe, 0 otherwise.
	Alr	Asset-liability ratio	Total liabilities divided by total assets.
Control variable	Irbr	Increasing rate of business revenue	Growth rate of current period operating revenue relative to previous period operating revenue.
	DL	Dual leadership	1 if the CEO also serves as chairman of the board.
	Bs	Board size	The logarithm of board members' number.
	Pid	Proportion of independent directors	The percentage of independent directors among all board members.

(5) Model building

Referring to existing research [23], the 'investment-investment opportunity' sensitivity approach is used to investigate the DTCB effect on enterprise investment efficiency. The basic logic of the model is to measure the investment efficiency of a firm by analyzing whether the investment opportunity in the current period matches the investment level in the next period. If the enterprise has high-return investment opportunities in the current period, and the enterprise invests more in the next period, it means that the corporate investment efficiency increases.

Therefore, corporate investment efficiency can be measured by the sensitivity of corporate investment behavior to investment opportunities. If DTCB increases the sensitivity, it indicates that DTCB improves corporate investment efficiency.

However, it should be noted that within China's institutional context, firms' ROA may be influenced by non-market factors, such as government subsidies, industrial policy support, regional preferential policies, and market distortions. These factors may prevent ROA from fully and accurately reflecting firms' underlying investment opportunities and growth potential, which constitutes an important limitation of the methodological approach adopted here.

Nevertheless, after controlling for a range of firm characteristics, year effects, and firm fixed effects, ROA is expected to capture, to a considerable extent, the information relevant to firms' investment opportunities, particularly in terms of its intertemporal variation and relative ranking across firms. In addition, the robustness checks, including the use of alternative measures and the exclusion of special samples, are designed to mitigate potential estimation bias arising from measurement error in the variables.

Eqs. (1)–(3) specify a two-way fixed effects model that is used to test Hypotheses 1 to 3.

$$\text{Ci}_{it} = C + \alpha_1 \text{Roa}_{it-1} + \alpha_2 \text{DTCBE}_{it} + \alpha_3 \text{Roa}_{it-1} \times \text{DTCBE}_{it} + \alpha_4 \text{Control}_{it} + \mu_1 + u_t + \varepsilon_{it} \tag{1}$$

$$\text{FC}_{it} = C + a_5 \text{DTCBE}_{it} + a_6 \text{Control}_{it} + \mu_i + u_t + \varepsilon_{it} \tag{2}$$

$$\text{Ac}_{it} = C + \alpha_7 \text{DTCBE}_{it} + \alpha_8 \text{Control}_{it} + \mu_1 + u_t + \varepsilon_{it} \tag{3}$$

In Eq. (1), Ci_{it} is current investment level of the enterprises. DTCBE_{it} is digital transformation index of commercial banks at the enterprise level. Roa_{it-1} is the return on assets in the lag period, reflecting the profitability of the enterprises. Usually, a highly profitable enterprise has a greater marginal return on investment and better investment opportunities [20]. Therefore, Roa_{it-1} can be used to measure investment opportunities. Control_{it} refers to control variables at the firm level including Ca, Cs, Soe, Alr, Irbr, Dl, Bs, Pid. α is the corresponding parameters, μ_i reflects the individual fixed effects, μ_t reflects the time fixed effects, ε_{it} is the residual term. This paper mainly observes the coefficient of $\text{Roa}_{it-1} \times \text{DTCBE}_{it}$ (α_3), which reflects the DTCB effect on corporate investment efficiency. If α_3 is significantly negative, DTCB significantly reduces corporate investment efficiency. In contrast, it means that DTCB has significantly improved the efficiency of enterprise investment.

In both Eq. (2) and Eq. (3), Fc_{it} and Ac_{it} represent corporate financing constraints and corporate agency costs respectively. All the other parameters and settings are also in accordance with Eq. (1). To control the impact of other factors on enterprise financing constraints and enterprise agency costs, this paper sets up a series of control variables in Eqs. (2) and (3) including Ca, Cs, Soe, Alr, Irbr, Dl, Bs, Pid.

4 Results and Discussion

4.1 Descriptive Statistics

Table 2 reports the descriptive statistics of the variables. The maximum and minimum values of DTCBE are 2.166 and 0.129, respectively, indicating substantial variation in the level of digital transformation across commercial banks, with some banks still exhibiting relatively low levels of digitalisation. The maximum and minimum values of Ci are 0.361 and 0.0002, respectively, while those of Roa are 0.256 and -0.363, respectively, suggesting considerable heterogeneity in firms' investment levels and profitability. The large variation in the key variables facilitates the identification of the effect of DTCB on corporate investment efficiency in the econometric analysis. The control variables also display reasonable dispersion across firms, reflecting differences in firm characteristics that may influence investment behaviour.

4.2 Baseline Results

Table 3 reports the baseline regression results. Prior to the regression analysis, multicollinearity diagnostics and normality tests were conducted. The results indicate no serious multicollinearity among the explanatory variables, and the distribution of the main variables is approximately normal.

The estimated coefficients on the interaction term between DTCBE and lagged ROA in Models (1) and (2) are positive and statistically significant, indicating that DTCB is associated with a stronger sensitivity of investment-to-investment opportunities. This provides empirical support for Hypothesis 1.

Several mechanisms may explain this relationship. First, the application of digital technologies enhances banks' information acquisition and processing capabilities, making it easier to identify firms with stronger profitability and growth potential. By extending credit to such firms, banks facilitate higher subsequent investment and thereby improve investment efficiency. Second, access to bank credit conveys positive signals about firm quality to the market, which may improve firms' access to alternative financing sources and further support investment [8]. Third,

digital technologies strengthen banks' monitoring and governance capacities, increasing external discipline on firms and reducing managerial opportunism, such as excessive perquisite consumption, which in turn improves investment efficiency [19].

Table 2. Summary statistics

Variable	N	Mean Value	Standard Deviation	Minimum	Maximum
Ci	14,509	0.0570	0.0609	0.0002	0.361
Roa	14,509	0.0294	0.0681	-0.363	0.256
DTCBE	14,509	1.222	0.335	0.129	2.166
Fc	14,509	-3.938	0.247	-4.753	-2.977
Ac	14,509	0.0859	0.0663	0.00696	0.641
Ca	14,509	3.003	0.299	1.792	3.689
Cs	14,509	22.27	1.178	19.63	26.44
Soe	14,509	0.306	0.461	0	1
Alr	14,509	0.451	0.195	0.0463	0.924
Irbr	14,509	0.158	0.402	-0.653	3.705
Dl	14,509	0.301	0.459	0	1
Bs	14,509	2.104	0.194	1.609	2.708
Pid	14,509	0.378	0.0545	0.286	0.600

Table 3. Baseline regression results

Variables	Model (1) C_i	Model (2) C_i
DTCBE × Roa_{t-1}	0.055***	0.040**
	(2.95)	(2.17)
Roa_{t-1}	-0.014	-0.012
	(-0.59)	(-0.52)
DTCBE	-0.024***	-0.004
	(-12.86)	(-1.48)
Ca		-0.068***
		(-12.23)
Cs		0.010***
		(8.31)
Soe		-0.008***
		(-2.82)
Alr		0.006
		(1.37)
Irbr		0.018***
		(16.92)
Dl		0.002*
		(1.73)
Bs		-0.003
		(-0.52)
Pid		-0.007
		(-0.47)
Constant	0.083***	0.038
	(38.18)	(1.32)
Individual FE	YES	YES
Year FE	YES	YES
N	14509	14509
R2	-0.239	-0.179

4.3 Robustness Checks

For robustness checks, municipalities directly under the central government are excluded from the sample. The samples of municipalities directly under the central government (MDUCG) were deleted for the robustness test.

This is due to the high degree of DTCB in MDUCG, which greatly improves their own loan technology. This may result in a large impact of DTCB on enterprise investment efficiency in MDUCG. Model (2) in Table 4 reports the regression results. The coefficient of DTCBE × Roa_{t-1} is significantly positive. Again, the core conclusions of this paper are robust.

Table 4. Robustness check results with alternative samples

Variables	C_i (Delete the Sample of MDUCG)
DTCBE × Roa_{t-1}	0.042**
	(1.99)
Roa_{t-1}	-0.013
	(-0.48)
DTCBE	-0.004
	(-1.46)
Controlled variable	YES
Individual FE	YES
Year FE	YES
Constant	0.019
	(0.57)
N	11504
R2	-0.181

4.4 Endogeneity Tests

The baseline results indicate that DTCB is associated with an improvement in corporate investment efficiency. However, these findings may be subject to potential endogeneity concerns. In particular, firms' investment behaviour may exhibit serial correlation, as current investment decisions are often influenced by past investment levels due to factors such as project continuity and path dependence in capital allocation.

If such persistence is not accounted for, the error term may capture the effect of lagged investment, which can lead to biased coefficient estimates. To address this concern, the one-period lag of the investment variable is included as an explanatory variable in the regression model. This specification allows the persistence in investment behaviour to be isolated, thereby enabling the estimated coefficient on DTCB to more accurately reflect its net effect on corporate investment efficiency. Accordingly, the lagged investment term is incorporated into the benchmark regression.

Table 5 reports the results of the endogeneity tests. In Models (1) and (2), the coefficient on the interaction term between DTCBE and lagged ROA remains positive and statistically significant. This indicates that the main findings remain robust after controlling for the potential serial correlation in firms' investment behaviour.

Table 5. Endogeneity test results

Variables	Model (1) C_i	Model (2) (Delete the Sample of the Municipality) C_i
NI_{t-1}	0.044***	0.042***
	(5.09)	(4.32)
DTCBE × Roa_{t-1}	0.037**	0.040*
	(2.01)	(1.90)
Roa_{t-1}	-0.016	-0.017
	(-0.71)	(-0.63)
DTCBE	-0.003	-0.004
	(-1.29)	(-1.38)
Controlled variable	YES	YES
Individual FE	YES	YES
Year FE	YES	YES
Constant	0.035	0.023
	(1.21)	(0.69)
N	14158	11224
R2	-0.175	-0.175

It should be noted that the approach of incorporating the lagged one-period investment level into the model has certain limitations. First, this method can only targetedly mitigate the endogeneity problem caused by the serial

correlation of investment, and it has no direct effect on addressing other sources of endogeneity such as reverse causality and omitted variables (e.g., the joint impact of unobservable factors like regional financial development on DTCB and corporate investment efficiency). Second, this method only controls for the investment inertia of the lagged first period and fails to cover the investment path dependence over a longer time horizon. If a firm's investment behavior exhibits the characteristics of multi-period continuous correlation, the introduction of a single lagged term cannot fully isolate the cumulative impact of historical investment. Despite these caveats, the consistency of the results across different model specifications and robustness checks lends credibility to the core conclusion that DTCB has a positive causal effect on corporate investment efficiency.

4.5 Mechanism Analysis

The theoretical analysis indicates that DTCB may improve corporate investment efficiency by easing financing constraints and reducing agency costs. Accordingly, the empirical analysis examines whether DTCB significantly alleviates financing constraints and lowers agency costs. The estimated coefficients on DTCBE in both specifications are negative and statistically significant, indicating that DTCB is associated with a reduction in both financing constraints and agency costs. These results provide empirical support for Hypotheses 2 and 3 (see Table 6).

To assess the economic magnitude of these mechanisms, the baseline regression results are used to compute their quantitative effects. A one-unit increase in DTCB is associated with an increase in corporate investment of approximately 0.052 through the easing of financing constraints and an increase of about 0.005 through the reduction of agency costs. These findings suggest that easing financing constraints and reducing agency costs constitute two important transmission channels through which DTCB enhances corporate investment efficiency, jointly accounting for part of the observed improvement in investment outcomes.

Table 6. Mechanism analysis results

Variables	FC	AC
DTCBE	-0.052***	-0.005**
	(-19.23)	(-2.16)
Controlled variable	YES	YES
Individual FE	YES	YES
Year FE	YES	YES
Constant	-2.023***	0.564***
	(-68.22)	(23.08)
N	14509	14509
R2	0.807	-0.056

4.6 Heterogeneity Analysis

This section examines whether the effect of DTCB on corporate investment efficiency differs between state-owned enterprises and privately owned firms. The results indicate that DTCB is associated with a significant improvement in investment efficiency among private enterprises, whereas no statistically significant effect is observed for state-owned enterprises (see Table 7). This pattern is consistent with Hypothesis 4.

Table 7. Results of heterogeneity analysis by firm ownership

Variables	C_i (State-owned Enterprise)	C_i (Private Enterprise)
DTCBE × Roa_{t-1}	0.028	0.056**
	(0.93)	(2.43)
Roa_{t-1}	0.017	-0.039
	(0.45)	(-1.34)
DTCBE	-0.003	-0.005
	(-0.70)	(-1.41)
Controlled variable	YES	YES
Individual FE	YES	YES
Year FE	YES	YES
Constant	-0.151***	0.082**
	(-3.31)	(2.21)
N	4447	10062
R2	-0.163	-0.214

The analysis focuses on firm ownership as the primary dimension of heterogeneity. As discussed in the literature, China's credit market is characterised by pronounced ownership-based discrimination, whereby state-owned enterprises benefit from implicit government guarantees and preferential access to bank credit, while private enterprises typically face more severe financing constraints. Ownership structure therefore serves as a direct indicator of differences in financing conditions and institutional treatment, which are central to the mechanisms through which DTCB influences investment efficiency.

Focusing on ownership heterogeneity provides a theoretically grounded and empirically relevant way to examine how the effects of DTCB vary across firms operating under systematically different institutional and market environments. Although other dimensions of heterogeneity, such as firm size, industry affiliation, or regional development, may also be important, ownership constitutes a fundamental cleavage in the Chinese context that directly relates to the core research question concerning credit allocation and financial access in the process of banking digitalisation.

5 Conclusion and Policy Recommendations

5.1 Conclusion

This study examines how the DTCB influences corporate investment efficiency using panel data on listed firms from 2013 to 2023. The results show that DTCB is associated with a significant improvement in corporate investment efficiency. This effect operates mainly through two channels. First, DTCB eases firms' financing constraints by improving information processing, risk assessment, and credit allocation. Second, DTCB reduces agency costs by strengthening external monitoring and governance mechanisms. Together, these channels improve firms' ability to convert investment opportunities into effective capital allocation.

The analysis further reveals that the positive effect of DTCB on investment efficiency is concentrated among privately owned enterprises, while no significant effect is observed for SOEs. This finding reflects the fact that private firms tend to face more severe financing constraints and information asymmetry, and therefore benefit more from improvements in banking digitalisation. Overall, the results provide empirical evidence that the DTCB reshapes firms' financing and governance environments in ways that affect investment outcomes.

5.2 Policy Implications

The findings suggest that DTCB improves corporate investment efficiency primarily by reducing information asymmetry and easing financing constraints. This implies that public policy can play an important role in supporting the institutional conditions under which digital transformation in banking can be most effective.

First, governments should promote the construction of information-sharing infrastructures to reduce information asymmetry between commercial banks and enterprises. Establishing integrated information-sharing platforms can facilitate the collection and exchange of enterprise-related data, including tax records, environmental and regulatory information, real estate and collateral data, administrative enforcement records, utility payment histories, and information on technological innovation and research activities. By improving data availability and interoperability, such platforms can enhance banks' ability to assess firm risk and performance, thereby supporting more efficient credit allocation.

Second, enterprises should be encouraged to undertake digital transformation in order to generate reliable and standardised operational data. Digitalisation of production, management, and internal control processes can improve information transparency and reduce firms' dependence on informal or relationship-based financing channels. However, the high fixed costs associated with digital transformation may discourage some firms, particularly SMEs, from investing in digital technologies. Targeted policy instruments, such as tax incentives, subsidies, and technical support programmes, can help lower these barriers and promote broader participation in digital transformation.

6 Limitations and Future Research

This study has several limitations that suggest directions for future research. Due to data constraints, the analysis is limited to listed firms, as information on the level of DTCB lending to unlisted firms is not currently available. As a result, the impact of DTCB on unlisted firms and SMEs cannot be directly examined.

In general, SMEs and unlisted firms tend to face more severe financing constraints, greater information opacity, and weaker formal governance structures than listed companies. For these firms, digital technologies such as big data-based risk assessment and alternative data credit scoring may play a particularly important role in improving access to finance and reducing information asymmetry. Consequently, the effects of DTCB on investment efficiency may be stronger for SMEs than those observed in this study. This implies that the estimated effects based on listed firms may underestimate the overall impact of banking digitalisation in the broader economy.

Future research could extend the analysis to unlisted firms if appropriate data become available, and could also explore additional dimensions of heterogeneity, such as firm size, industry characteristics, or regional institutional environments. Such extensions would contribute to a more comprehensive understanding of how digital transformation

in banking affects corporate investment and economic efficiency across different organisational and institutional contexts.

Author Contributions

Funding

Data Availability

The data used to support the research findings are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflict of interest.

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