

Science and Technology Finance Policy and Corporate Investment Efficiency -- A Quasi-Natural Experiment Based on Pilot Policies for Integrating Technology with Financer

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Abstract. In the context of China's economic transformation and rapid technological advancement, based on the implementation of the "Pilot Policy for Promoting the Integration of Technology and Finance", this paper constructs a panel data of prefecture-level cities in China from 2005 to 2017, and examines the impact and mechanism of science and technology finance policy on the corporate investment efficiency by using the DID method. The DID method is used to investigate the impact and mechanism of technology finance policy on the corporate investment efficiency. It is found that the science and technology finance policy significantly improves the corporate investment efficiency, and this conclusion remains valid after a series of robustness tests such as the parallel trend test, the placebo test, and the Propensity Score Matching-Difference in Differences (PSM-DID) analyses. Further mechanism analysis in this paper reveals that the science and technology finance policy mainly enhances the corporate investment efficiency by alleviating the corporate financing constraints, promoting the digital transformation of enterprises, and increasing the capitalized R&D investment of enterprises. In addition, the effect of the implementation of science and technology finance policy has a certain degree of heterogeneity, and this policy has a more significant impact on the improvement of investment efficiency of non-state-owned enterprises and large enterprises. This paper delves into the impact of technology finance on the investment behavior of micro-enterprises, providing theoretical support and empirical guidance for the advancement of science and technology finance practices and high-quality economic development.

Keywords: science and technology finance policy, corporate investment efficiency, DID method.

1. Introduction

Under the new normal of China's economy, innovation and technological development have become the core driving force for the country's sustained growth. Financial policy, as an essential tool for national macroeconomic regulation and control, plays a decisive role in guiding resource allocation, stimulating market vitality and promoting technological innovation. The 20th CPC National Congress report highlighted innovation as the primary driving force, emphasizing its central role in China's modernization efforts and advocating for an improved technological innovation system. Additionally, the Central Economic Work Conference encouraged enhancing the positive interplay between technology, industry, and finance. In an important speech at the Central Financial Work Economic Conference in October 2023, General Secretary Xi Jinping underlined the significance of excelling in various financial sectors, including technology finance, green finance, inclusive finance, pension finance, and digital finance. The meeting stressed the importance of science and technology finance and proposed a strategy to intertwine technological and financial development. This involves refining the financial market system and leveraging the strengths of diverse financial institutions such as banks, insurance, and securities, to create a synergistic, efficient, and competitive financial environment. Indeed, China had already started the practice of technology finance as early as 2011, and the adjustment, innovation and deepening of technology finance policies will have a profound impact on the micro-behavior of enterprises. However, there is a lack of in-depth empirical research and theoretical discussion on the specific impact and mechanism of these new financial methods on the investment behavior of enterprises, especially their adaptability and efficiency in different stages and fields, which is necessary for in-depth research and discussion.

China's economy has transitioned from a stage of high-speed growth to a phase of high-quality development. In this context, getting rid of an over-reliance on investment and improving the investment efficiency utilization at the macro level are vital pathways for transforming and upgrading the economic development model and achieving high-quality development. The enhancement of macro-level investment efficiency is inseparable from micro-level entities. How micro-enterprises can improve the efficiency of resource allocation in investment processes has long been an important topic of interest in the academic community. In the current era of deepening economic and social development, enterprises increasingly need to rely on cutting-edge technological innovation activities, represented by digital technologies, to improve resource allocation efficiency. Technology finance can help enterprises enhance their innovation capabilities, improve internal governance, promote the transformation of production modes, and thereby increase investment efficiency, by integrating financial resources. Whether the implementation of technology finance policies can improve enterprise investment efficiency, enhance corporate competitiveness, and promote high-quality development remains an unanswered question.

In order to address this question, this study leverages the "Pilot Program for Promoting the Integration of Technology and Finance" implemented by the People's Bank of China and other departments as an exogenous policy shock. Utilizing panel data of Chinese prefecture-level cities from 2005 to 2017, the study employs the DID method to examine the impact of science and technology finance policies on the efficiency of corporate investment and its operational mechanisms. The research substantiates that science and technology finance policies significantly enhance the investment efficiency of firms.

This study makes several marginal contributions. Firstly, it examines the impact of science and technology finance on the investment behavior of micro-enterprises, providing empirical evidence that enriches the understanding of science and technology finance's influence on micro-enterprises. Secondly, the study integrates technology finance with pilot policies as an exogenous policy shock, employing a progressive DID method to identify the causal relationship between the implementation of technology finance policy and corporate investment efficiency. This approach helps mitigate issues such as reverse causality and omitted variable biases. The robustness of causal identification is further validated through methods like placebo tests, resulting in more accurate policy assessment outcomes. Thirdly, the research holds practical significance, offering empirical insights for China's future practice in technology finance. It bears important implications for the nation's strategic planning in fostering innovation-driven, high-quality development, and in promoting financial services to the real economy.

The remainder of this paper is organized as follows: Part II provides a literature review and theoretical analysis. Part III describes the research design, along with descriptive statistics of the sample and relevant variables. Part IV reports the basic empirical results and conducts robustness checks. Part V analyzes the mechanisms of influence. Part VI summarizes the conclusions and offers policy recommendations.

2. Literature Review and Theoretical Analysis

The academic community, both domestically and internationally, has amassed a substantial body of research concerning the efficiency of corporate investments. Primarily, the definition of investment efficiency, as posited by neoclassical investment theory, is that the optimal level of investment is attained when the marginal return on capital equals the marginal cost (Jorgenson, 1963). Managers making investment decisions are influenced by factors such as the complexity of the macro environment and information asymmetry, leading to what is termed "inefficient investment." This inefficiency is chiefly characterized by either excessive investment or insufficient investment. The efficiency of corporate investments is subject to the influence of multiple factors, broadly categorized into macro and micro-level factors. At the macro level, existing research, grounded in the unique macroeconomic and political milieu of China, identifies government intervention, industrial policies,

and institutional frameworks as pivotal factors influencing the efficiency of corporate investments. In the realm of government intervention, Chen and Huang (2019) examined the impact of stock market liberalization on corporate investment efficiency using the Shanghai-Hong Kong Stock Connect as a quasi-natural experiment. They concluded that the opening of stock markets enhances the investment efficiency of firms and bolsters their ability to serve the real economy. Similarly, Li et al. (2015) posited that reducing the level of government intervention also contributes to the enhancement of corporate investment efficiency. This corpus of research aligns with a broader academic consensus, highlighting the intricate interplay between market dynamics and regulatory frameworks in shaping the investment landscape within business sectors.

Secondly, in terms of the impact on economic policy, certain studies have approached this from the perspective of economic policy uncertainty. Rao et al. (2017), drawing upon the "Economic Policy Uncertainty Index" developed by Baker et al. (2016), investigated the effects of China's economic policy uncertainty on corporate investment and investment efficiency. Their findings indicate that heightened economic policy uncertainty leads to a significant reduction in corporate investment, while investment efficiency improves as economic policy uncertainty increases. Other literature has explored this from the perspective of monetary policy, demonstrating that a relaxed monetary policy alleviates financing constraints for private enterprises, thereby enhancing investment efficiency (Shen et al., 2012; Jin et al., 2012; Liu et al., 2014). Yu et al. (2014) observed that recent frequent shocks to monetary policy have intensified financing constraints among non-state-owned enterprises. State-owned enterprises continually receive supportive credit subsidies, whereas the credit resources for non-state-owned enterprises are correspondingly squeezed out, leading to a persistent decline in the investment rate of non-state-owned enterprises. Regarding industrial policy, Li Wenjing and Li (2014) discovered that when companies are incentivized by industrial policy, private enterprises are more likely to break through industry barriers and obtain greater banking financing support, thereby expanding their investments. However, industrial policy regulation conducted through administrative means tends to reduce investment efficiency. Zhang et al. (2017) utilized a difference-in-differences model to dynamically examine the impact of provincial government-released industrial policies on the financing constraints of local listed companies from both the supply and demand perspectives of funds. They concluded that the introduction of industrial policies diminishes the investment efficiency of enterprises.

Once more, an increasing volume of scholarly inquiries has turned its attention to the impact of macro-financial factors on corporate investment efficiency, unfolding investigations in realms such as financing constraints and financial development. The study by Chen et al. (2015) discerns that under a semi-mandatory dividend policy, the decisions regarding cash dividends enhance the investment efficiency and amplify the financing constraints for firms with refinancing needs. Conversely, for firms devoid of such needs, these decisions fail to alter investment sensitivity nor mitigate the propensity for excessive investment sensitivity. Wan (2013) observed that enhancements in the legal institutional framework positively influence corporate investment efficiency to a certain extent. Furthermore, in the wake of the ascendancy of digital finance, a segment of academia has probed into its repercussions on corporate investment efficiency. Liu et al. (2022) discerned that digital finance alleviates investment insufficiency in firms but exacerbates excessive investment. Notably, the mitigative effect of digital finance on insufficient investment predominantly transpires through the amelioration of corporate financing constraints, as corroborated by studies from Wan et al. (2022) and Zhang et al. (2015).

At the microeconomic level, extant research on corporate investment efficiency predominantly concentrates on perspectives of information asymmetry and agency costs. In the realm of information asymmetry, Zhang and Lü (2009) identified that an elevation in the level of information disclosure and the evolution of information intermediaries can alleviate the degree of information asymmetry, thereby enhancing corporate investment efficiency and curbing excessive investment activities. Li et al. (2022) empirically examined the impact and operational mechanisms of digital transformation on corporate investment efficiency. They discovered that digital transformation mitigates the

information asymmetry between corporations and external entities, reduces agency costs, and significantly suppresses excessive investment while alleviating investment insufficiency, consequently augmenting investment efficiency.

In the realm of agency costs, Fama (1980) highlighted the issue of managerial self-serving behavior due to information asymmetry between shareholders and executives, leading to inefficient investments. Jensen (1986) argued that managers, driven by the desire to establish a 'private empire' and expand company size, may tend toward overinvestment, thereby diminishing the efficiency of corporate investments. Pan et al. (2019) found that the influence of chain shareholders on corporate investment efficiency is significant, primarily manifesting in the form of 'competitive collusion' leading to insufficient industry investment. Roychowdhury (2006) observed the possibility of managerial 'myopia', where, facing the prospect of disclosing financial losses, some firms may opt to cut their R&D expenditure, resulting in underinvestment. Moreover, it has been discovered that management might overly prioritize their self-interest and shy away from taking on higher risks, even if these risks could yield high positive net present values, a phenomenon known as 'risk aversion', which could, in the long term, lead to a total investment level below the ideal state (Amihud & Lev, 1981; Gormley & Matsa, 2016). Additionally, from the novel perspective of bank-firm relationships and controlling financial institutions, Zhai et al. (2014) demonstrated that bank-firm relationships, as an informal alternative mechanism, help improve the investment efficiency of private listed companies. Li and Ma (2014) pointed out that firms controlling financial institutions reduce the resource allocation efficiency of financial institutions to the controlled enterprises.

In recent years, as digital technologies like the internet, big data, and cloud computing increasingly permeate various sectors of economic and social development, there has been growing research interest in how digital transformation affects corporate investment efficiency. On one hand, the rise and development of platform businesses have made transaction and financial data more accessible, significantly mitigating the problem of information asymmetry (Qi, 2020), reducing costs associated with information search, contract development, and contract fulfillment (Zhao et al., 2021), and simultaneously improving the quality of information disclosure (Zhang et al., 2021). Empirical studies by Liu and Yang (2022) have found that the digitalization level of listed companies can enhance corporate investment efficiency by reducing management expenses and improving asset operation efficiency. Hu (2022) discovered that digitalization positively affects the efficiency of corporate resource allocation, with a more pronounced effect in firms with higher managerial agency problems and those in highly competitive industries.

Therefore, overall, existing research has demonstrated that financial factors, including the financial system and markets, influence corporate investment efficiency at both the macro and micro levels. Techno-finance, a system comprising a series of financial tools, institutions, policies, and services designed to promote technological innovation (Zhao et al., 2009), has been a key area of financial development in recent years and is poised to have a profound impact on corporate investment efficiency.

China has conducted certain practices in techno-finance, providing a valuable exogenous policy shock for empirical research, akin to a quasi-natural experiment. In December 2010, the Ministry of Science and Technology, the People's Bank of China, and other relevant departments issued the "Notice on the Issuance of the Pilot Implementation Plan for Promoting the Integration of Science and Finance", initiating the "Pilot Work for Promoting the Integration of Science and Finance." This initiative involved the implementation of various financial measures to support the development of technology-based enterprises. As a natural exogenous shock, studies utilizing these pilot policies as natural experiments can address potential endogeneity issues. For instance, Hu (2015), using urban panel data from 2005 to 2017 and employing the DID method, examined the impact and mechanism of China's techno-finance policies implemented post-2011 on industrial structure transformation and upgrading. The study found that these policies significantly promoted the transformation and upgrading of industrial structures in pilot cities, with policy effectiveness increasing over time. Technological innovation and financial development played mediating roles in this process. Shen et

al. (2022), treating this policy as a quasi-natural experiment and based on panel data of China's A-share listed real enterprises, explored the impact of the techno-finance integration pilot policy on the digital transformation of real enterprises and its mechanisms. They found that the pilot policy significantly enhanced the level of financial technology development in regions, thereby promoting the digital transformation of real enterprises. Chen et al. (2021) discovered that the implementation of techno-finance policies could alleviate financing constraints and improve financial stability, thereby aiding the digital transformation of enterprises. This promotion effect showed significant heterogeneity; the techno-finance policies provided a substantial impetus for digital technology application in non-state-owned and high-tech enterprises. In a subsequent study, Chen et al. (2022) also based on this policy, found that its implementation effectively enhanced the willingness and investment of enterprises in applying digital technologies.

3. Data, Empirical Design, and Variable Description

3.1. Data

The data sources for this study are twofold: firstly, the pilot policies for science and technology and finance were obtained from the official websites of the Ministry of Science and Technology and the People's Bank of China; secondly, the investment data of enterprises and related financial data were derived from the CSMAR database of Guotai An and the Wind database. The data were processed as follows: initially, all ST and ST* listed companies were excluded, followed by the removal of listed companies in the financial sector, retaining only non-financial listed enterprises. Additionally, tailoring was applied to the control variables at the enterprise level at the upper and lower 1% to mitigate the impact of outliers on the analysis results. This study has compiled a panel dataset of 3468 non-financial listed companies from 2007 to 2019.

3.2. Empirical Design

This article is predicated on a quasi-natural experiment, which is based on two batches of pilot projects combining finance and technology, jointly conducted by the Ministry of Science and Technology and the People's Bank of China in 2011 and 2016. An empirical study was conducted using a progressive DID model. The regression equation is presented as follows:

$$Eff_{it} = \beta * post_t * treated_i + X_{it} * \gamma + u_i + \varepsilon_{it} \quad (1)$$

In this equation, Eff_{it} represents the investment efficiency of firm 'i' in year 't'; $post_t$ is a time dummy variable, assigned a value of 1 post-policy implementation year and 0 otherwise; $treated_i$ signifies the policy dummy variable, assigned a value of 1 if the firm's city is included in the pilot, and 0 otherwise; X_{it} denotes other control variables; and u_i represents city-specific fixed effects.

3.3. Variable Description

3.3.1 Investment Efficiency Indicators

The current methods for measuring the efficiency of corporate capital investment primarily include the Wurgler model, the Marginal Tobin's Q model, and the Richardson model. This article adopts the method of Richardson (2006) for measuring corporate investment efficiency. It also references the variables influencing investment selected by Li et al. (2015) and Hu et al. (2019). The specific equation is as follows:

$$Inv_{it} = \alpha_0 + \alpha_1 Inv_{it-1} + \alpha_1 asset_{it-1} + \alpha_1 cash_{it-1} + \alpha_1 leve_{it-1} + \alpha_1 roa_{it-1} + \alpha_1 ficc_{it-1} + u_i + e_t + \varepsilon_{it} \quad (2)$$

$$Inv_{it} = \alpha_0 + \alpha_1 treat_i post_t + \alpha_1 asset_{it-1} + \alpha_1 cash_{it-1} + \alpha_1 leve_{it-1} + \alpha_1 roa_{it-1} + \alpha_1 ficc_{it-1} + u_i + e_t + \varepsilon_{it} \quad (3)$$

The underlying concept of this measurement method involves regressing the corporate investment amount against variables that influence normal corporate investment, thereby obtaining the corporate investment amount as fitted by the model. The deviation of the actual corporate investment amount

from the model-fitted value, i.e., the residual of the model, represents the degree to which a firm deviates from the optimal investment level. Finally, the absolute value of this residual is used as a measure of corporate investment efficiency. In the following text, this indicator is denoted as Eff_{ift} . A larger value of this indicator implies poorer corporate investment efficiency.

Specifically, Inv_{ift} represents the investment level in year t of firm f in industry i , calculated by subtracting the income from the disposal of fixed assets, intangible assets, and other long-term assets from the expenditure on constructing fixed assets, intangible assets, and other long-term assets, and then dividing by the total assets of the firm. Inv_{ift-1} represents the lagged investment level of a firm, $asset_{ift-1}$ denotes the total assets of the firm in the preceding period, $cash_{ift-1}$ indicates the firm's monetary funds from the previous period, $leve_{ift-1}$ is the debt-to-asset ratio of the firm in the lagged period, roa_{ift-1} signifies the return on assets from the prior period, and $ficc_{ift-1}$ corresponds to the free cash flow of the firm in the preceding period.

3.3.2 Pivotal Explanatory Variable

The pivotal explanatory variable is delineated as the interaction term between temporal and policy dummy variables. This term is operationalized as unity 1 when the enterprise, situated within a prefecture-level city, falls under the ambit of the pilot program in the designated year. In all other scenarios, the term is assigned a null value 0.

3.3.3 Mechanism variables

(1) Digital Transformation (digital)

The variable of mechanism under scrutiny in this research is Digital Transformation (digital). Drawing upon the methodology delineated by Wu et al. (2021), this study quantifies digital transformation within corporations through an analysis of the frequency of pertinent keywords within the annual reports of publicly listed companies. This analysis is underpinned by a meticulously curated lexicon, informed by Wu et al. (2021), encompassing terminologies pertinent to artificial intelligence, big data, cloud computing, blockchain, and digital technology applications.

The data processing phase involves the acquisition and subsequent textual extraction from annual reports of all A-share listed companies in China, utilizing Java-based PDF tools. This is followed by a comprehensive text preprocessing routine, which includes segmentation, elimination of stop words, and exclusion of contexts where negation precedes the keywords. The culmination of this process is the aggregation and logarithmic conversion of the frequency of selected terms, thus yielding a nuanced and holistic metric for assessing corporate digital transformation.

(2) Financing Constraints (KZ)

This study aligns with the foundational research conducted by Kaplan and Zingales (1997) and adopts the KZ Index as a quantifier of financing constraints. This index has gained extensive application and recognition within the scholarly community (Li and Han, 2019; He and Zhang, 2021). A higher index value is indicative of more pronounced financing constraints experienced by an enterprise.

(3) Research and Development Mechanism (rd)

This research operationalizes corporate innovation investment through the log-transformed values of research and development expenditures reported by publicly listed companies.

3.4. Control Variables

In light of the potential significant impact of various other factors within a corporation on investment efficiency, this study introduces a series of corporate characteristic indicators as control variables to mitigate the endogeneity issue arising from omitted variables. Drawing on existing literature, the following control variables are incorporated into DID model: (1) Company Size (Size), representing the scale of the corporation; (2) Leverage Ratio (Lev), indicating the overall debt-to-asset ratio of the corporation; (3) Return on Assets (ROA), reflecting the profitability of the corporation; (4) Revenue Growth from Main Operations (Growth), denoting the growth potential of

the corporation; (5) Board Size (Board), indicative of corporate governance; (6) Tobin's Q (TobinQ), representing the value of the corporation; (7) Current Ratio (ldbl), illustrating the corporation's ability to pay off its short-term liabilities.

Table 1. Summary statistics

Variable Name	Variable Definition	Variable Description
eff	Corporate Investment Efficiency	Difference between the actual corporate investment and the model-estimated
digital	Digital Transformation	Refer to Wu Fei et al. (2022) Constructing textual information
KZ	Financing Constraints	KZ index as a measure of financing constraints
rd	Research and Development Mechanism	Logarithmic value of R&D investment
Size	Company Size	ln(total assets)
Lev	Leverage Ratio	Total liabilities/total assets
ROA	Return on Assets	Net profit after tax/total assets
Growth	Revenue Growth from Main Operations	(Revenue for the Current Period — Revenue for the Previous Period)/Revenue for the Previous Period
Board	Board Size	ln(Number of Board of Directors)
TobinQ	Tobin's Q	(share value*number of outstanding shares+ net assets per share*number of shares not outstanding + book value of liabilities)/Total assets
ldbl	Current Ratio	Current assets/current liabilities

3.5. Descriptive Statistics

Table 2 presents the descriptive statistics for the regression sample utilized in this study. The mean value for corporate investment efficiency (eff) is 0.0346, indicating a prevalent level of suboptimal investment across the sample firms, with ample room for enhancement in average investment efficiency. Additionally, a standard deviation of 0.0301 points to significant disparities in inefficient investment practices among these enterprises.

Table 2. Descriptive Statistics

Variables	N	Mean	SD	Min	Max
eff	20,476	0.0346	0.0301	0.0000	0.3667
policy	27,052	0.4670	0.4989	0.0000	1.0000
Size	27,052	22.0663	1.2728	19.8853	25.8301
Lev	27,052	0.4213	0.2054	0.0553	0.8673
ROA	27,051	0.0484	0.0552	-0.1470	0.2085
Growth	25,267	0.1818	0.3726	-0.4935	2.1684
Board	26,973	2.1446	0.1993	1.6094	2.7081
TobinQ	26,547	1.9739	1.1310	0.8972	7.2298
ldbl	27,052	2.5624	2.7987	0.3029	18.0528
digitalA	26,645	1.2255	1.3473	0.0000	6.3008
KZ	26,592	0.9310	2.3348	-11.2318	13.6623

4. Empirical Findings

4.1. Baseline Regression Results

Table 3 delineates the results of a progressive DID test assessing the impact of science and technology finance policy on investment efficiency. Column 1 of the table reveals that the regression coefficient for the science and technology finance (policy) is -0.0036, significant at the 1% level. Column 2 builds upon this foundation by incorporating controls for individual fixed effects (Industry FE) and provincial fixed effects (Province FE), where the regression coefficient of the technology finance policy is -0.0043, also significant at the 1% level. Column 3 further integrates corporate characteristic indicators as control variables, maintaining the policy's regression coefficient at -0.0019, which remains significantly negative at the 1% level. The regression outcomes consistently

demonstrate that, irrespective of the control for fixed effects or the inclusion of control variables, the coefficient of the science and technology finance policy is significantly negative. This suggests that the implementation of science and technology finance policy can enhance corporate investment efficiency.

The pilot policy of integrating science and technology with finance is effective in reducing corporate inefficient investments and enhancing investment efficiency for several reasons. Firstly, the technology finance policy significantly improves the financing environment for enterprises. From an investment and financing perspective, alleviating financial constraints enhances corporate investment efficiency (Wan, et al., 2022; Zhang, et al., 2015). The implementation of science and technology finance policy effectively eases these constraints (Hu, 2015), thereby driving an increase in investment efficiency. Secondly, the policy fosters digital transformation and the upgrading of industrial structures. Pilot policies combining technology and finance significantly promote the digital transformation of physical enterprises (Shen, 2022; Hu, 2015). Digital transformation, by incorporating technologies like big data, artificial intelligence, and the Internet of Things, enhances competitiveness and better aligns with market trends and customer needs, leading to more optimal investment scales and improved investment efficiency. Thirdly, science and technology finance policy continuously strengthens innovation input and output quality, thereby boosting investment efficiency. With the advancement of science and technology finance policies, there is an ongoing enhancement in corporate R&D expenditure and the quality of innovative outputs. The implementation of such policies effectively increases the willingness and investment of enterprises in applying technological advancements, indicating that technology policy not only offers technical support but also encourages technological innovation and application (Chen, et al., 2022). Additionally, technology finance has a more positive impact on technology-oriented enterprises. On one hand, the execution of technology finance policy strengthens financial stability (Chen, et al., 2021), giving firms more confidence in long-term R&D and innovative investments. On the other hand, it encourages cooperation between financial institutions and technology-oriented enterprises, providing tailored financial products and services. Such collaborations better meet the funding needs of enterprises, making their investments more precise and effective.

Table 3. Baseline Regression Results

VARIABLES	(1) eff	(2) eff	(3) eff
policy	-0.0036*** (-6.83)	-0.0043*** (-7.37)	-0.0019*** (-3.17)
Size			-0.0037*** (-12.72)
Lev			0.0208*** (10.11)
ROA			0.0301*** (6.28)
Growth			0.0015*** (2.67)
Board			-0.0001 (-0.09)
TobinQ			-0.0009*** (-4.20)
ldbl			-0.0002 (-1.48)
Constant	0.0368*** (75.48)	0.0472*** (17.88)	0.1221*** (16.26)
Observations	20,476	20,476	20,062
Number of id	2,960	2,960	2,959
Industry FE	NO	YES	YES
Province FE	NO	YES	YES

Note: Parenthetical figures represent robust standard errors clustered at the regional level. Asterisks indicate statistical significance at the levels of *** 1%, ** 5%, and * 10%, respectively. Similar notations are employed subsequently.

4.2. DID Setting Validity Test: Parallel Trend Test

The precondition for policy evaluation using the DID method is the satisfaction of the parallel trends assumption. This study, drawing on the approach of Beck and Levine (2007), conducts a parallel trends test for the model. The results, as illustrated in Figure 1, indicate no significant difference in investment efficiency between the treatment and control groups in the years preceding the policy implementation (i.e., 2008-2011), suggesting that the research design of this paper reasonably satisfies the parallel trends assumption. In the years following the policy implementation (i.e., 2012-2017), the regression coefficients are significant, with the experimental and control groups exhibiting notable differences in investment efficiency. This implies that the implementation of the science and technology finance policy can effectively enhance corporate investment efficiency.

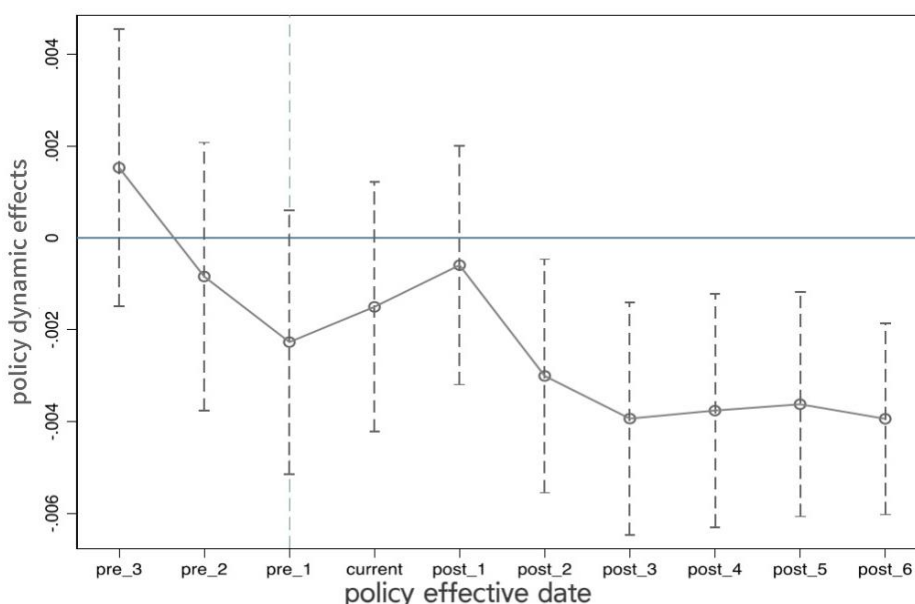


Fig. 1 Parallel trend test

4.3. Validity Test of DID Setting – Placebo Test

Another concern regarding the identification assumption of DID method is the potential impact of other unobservable, time-varying urban characteristics on the estimation results. This study addresses this concern by conducting a placebo test through random assignment of treatment and control groups, examining whether omitted variables could lead to differences in regression outcomes.

Specifically, the study conducts a placebo test for the implementation of the pilot policy on the integration of science and technology finance by randomly dividing treatment and control groups. This random division process is repeated 500 times, and the results of each regression are recorded. Since the placebo group is randomly generated and not influenced by the actual policy, the 'false' policy dummy variable should not have a significant impact on the dependent variable, and its coefficient should be near zero. As depicted in Figure 2, the mean of the entire distribution is near zero, and the distribution significantly differs from the coefficients of the baseline regression, being far removed from those results. This indicates that the research design of this paper passes the placebo test.

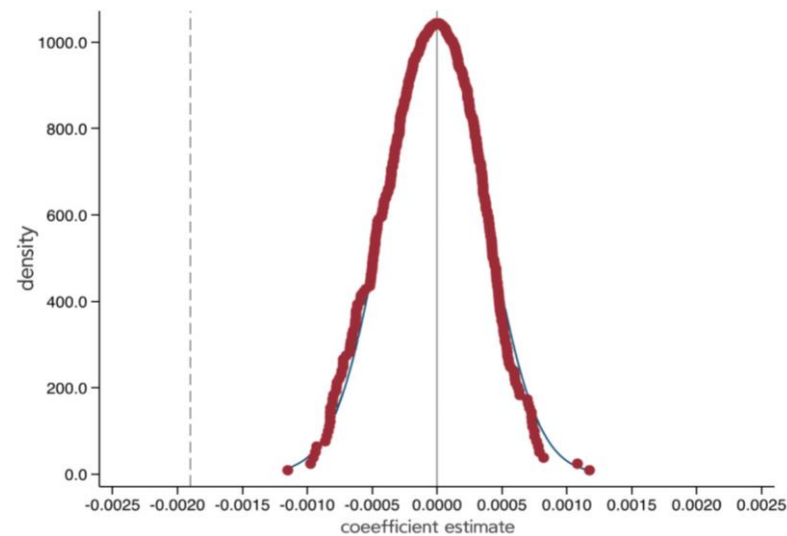


Fig. 2 Placebo test

4.4. Additional Robustness Tests

This study further conducts robustness tests on the baseline regression results. Firstly, considering that the reliability of DID estimates might be contingent upon the selection of the control group, the study utilizes the PSM-DID model for regression estimation. The study enterprises in the science and technology finance pilot areas are treated as the experimental group, while other enterprises serve as a preparatory treatment group. Variables such as firm size, leverage ratio, and profitability are used for matching, and the matched sample is subjected to regression akin to the baseline model. Secondly, acknowledging potential issues of self-selection due to the delisting of firms with exceptionally low investment efficiency and the listing of new firms during the 2007-2019 sample period, the study retains only those corporate variables that are consistently present throughout this period, thereby constructing a balanced panel dataset. In all regressions, the coefficient of the policy variable remains significantly negative, indicating that the baseline regression is robust to a certain extent.

Table 4. Additional Robustness Tests

VARIABLES	PSM-DID		Balance panel	
	(1) eff	(2) eff	(3) eff	(4) eff
policy	-0.0039*** (-5.54)	-0.0019*** (-2.71)	-0.0044*** (-6.48)	-0.0022*** (-3.01)
Size		-0.0037*** (-11.18)		-0.0023*** (-6.13)
Lev		0.0198*** (8.46)		0.0164*** (5.83)
ROA		0.0335*** (5.98)		0.0201*** (2.77)
Growth		0.0017** (2.53)		0.0024*** (3.08)
TobinQ		-0.0010*** (-3.95)		-0.0005 (-1.38)
ldbl		-0.0002 (-0.99)		-0.0004 (-1.39)
Constant	0.0447*** (16.35)	0.1188*** (14.24)	0.0456*** (15.39)	0.0834*** (8.46)
Observations	14,983	14,983	10,136	9,936
Number of id	2,870	2,870	921	921
Industry FE	YES	YES	YES	YES
Province FE	YES	YES	YES	YES

5. Mechanism Analysis and Heterogeneity Analysis

5.1. Mechanism Analysis: Financing Constraint Mechanism

Table 5 presents a mechanism analysis of the impact of the science and technology finance policy on corporate investment efficiency. Firstly, the science and technology finance policy directly alters the financing environment of firms, and financing constraints are a key factor influencing corporate investment. This study initially refers to Kaplan and Zingales (1997), employing the KZ index as a measure of financing constraints, an indicator widely used in academic circles (Li and Han, 2019; He and Zhang, 2021). The higher this index, the greater the degree of financing constraints faced by a firm.

This study, drawing on Jiang(2022) approach for mechanism analysis, examines the impact of science and technology finance policy on financing constraints. Regression of the policy variable against financing constraints is conducted, with Column 1 excluding any control variables and fixed effects, Column 2 adding individual fixed effects and provincial fixed effects based on Column 1, and Column 3 further incorporating corporate characteristic indicators as control variables, as shown in Table 4. The regression results consistently demonstrate that the coefficient of the science and technology finance policy is significantly negative in all models, indicating that the policy relaxes corporate financing constraints, thereby enhancing investment efficiency.

The implementation of the science and technology finance policy aims to promote technological innovation and research and development activities, broadening financing channels for enterprises and thereby alleviating their financing constraints. Governments and financial institutions offer specific low-interest loan schemes or direct subsidies to reduce the financial burden on enterprises, enabling them to allocate more resources to technological research and development. As financing constraints diminish, enterprises are better positioned to capitalize on investment opportunities in the market, thus increasing their investment efficiency.

Table 5. Financing Constraint Mechanism Analysis

	(1)	(2)	(3)
VARIABLES	KZ	KZ	KZ
policy	-0.0950*** (-3.13)	-0.0725** (-2.34)	-0.1183*** (-3.48)
Size			-0.0561*** (-3.44)
Lev			2.1232*** (18.68)
ROA			-3.3870*** (-12.49)
Growth			0.0763** (2.45)
Board			-0.0883 (-1.06)
TobinQ			-0.0099 (-0.81)
ldbl			-0.0359*** (-5.22)
Constant	0.6611*** (16.68)	0.6080*** (2.63)	1.6242*** (3.84)
Observations	26,592	26,592	24,275
Number of id	3,220	3,220	3,052
Industry FE	NO	YES	YES
Province FE	NO	YES	YES

5.2. Mechanism Analysis: Corporate Digital Transformation Mechanism

Table 6 presents the mechanism analysis of corporate digital transformation. Column 1 of the table shows results without any control variables and fixed effects. Column 2 includes controls for individual fixed effects and provincial fixed effects, and Column 3 further adds corporate

characteristic indicators as control variables. The regression results indicate that the coefficient of the science and technology finance policy is significantly negative across all models, with significance at the 1% level. This suggests that the science and technology finance policy can enhance the degree of digital transformation in enterprises, thereby improving their investment efficiency.

As one of the forefront technologies in current socio-economic development, the science and technology finance policy provides robust support for enterprises to develop, utilize digital technologies, and undertake digital transformation. Firstly, the science and technology finance policy facilitates corporate digital transformation by influencing digital technologies and expanding service scopes. It enhances the convenience of financial support, lays the foundation for institutional digital transformation, and drives the construction of next-generation information technology infrastructure, accelerating the transformation of business processes. Secondly, the policy fosters a deep integration of new-generation information technologies such as the internet, big data, and artificial intelligence with the real economy. This integration propels the concurrent development of the real economy and the digital economy, leveraging digital finance to support the development and application of a modernized economic system, thereby hastening the progress of the digital economy and corporate digital transformation.

Digital transformation, by enhancing information transparency and data analytics capabilities, optimizes resource allocation, thereby improving corporate investment efficiency. Firstly, through digital transformation, enterprises can enhance information transparency and reduce information asymmetry. This aids management in accessing more diversified information, diminishing unknown investment risks, and making investments more precise and objective, thus enhancing investment efficiency. Secondly, corporate digital transformation provides more comprehensive data analysis and decision-making support. Data analytics help enterprises more accurately understand market trends, customer needs, and investment risks, enabling more precise resource allocation and optimization. This improves the utilization of funds, consequently elevating investment efficiency.

Table 6. Corporate Digital Transformation Mechanism Analysis

VARIABLES	(1) digital	(2) digital	(3) digital
policy	0.1504*** (8.56)	0.1060*** (5.98)	0.1078*** (5.38)
Size			0.0044 (0.44)
Lev			-0.0178 (-0.27)
ROA			0.2695* (1.75)
Growth			0.0197 (1.14)
Board			-0.0561 (-1.12)
TobinQ			-0.0032 (-0.46)
ldbl			-0.0049 (-1.25)
Constant	1.2489*** (57.37)	1.2538*** (11.39)	1.2468*** (4.68)
Observations	26,634	26,634	24,310
Number of id	3,226	3,226	3,058
Industry FE	NO	YES	YES
Province FE	NO	YES	YES

5.3. Mechanism Analysis: Research and Development Mechanism

Table 7 displays the analysis of the research and development mechanism, conducting regressions with total R&D expenditure, capitalized R&D expenditure, and expensed R&D expenditure as the

dependent variables. Columns 1, 3, and 5 include controls for individual fixed effects and provincial fixed effects without any other control variables, while Columns 2, 4, and 6 further incorporate corporate characteristic indicators as control variables. The regression results indicate that the coefficients of the policy dummy variable are significantly positive in Columns 1 to 4, but not significant in Columns 5 and 6. This suggests that the science and technology finance policy can enhance total corporate R&D as well as capitalized R&D spending, but it does not have a significant impact on expensed R&D expenditure.

The primary objective of the science and technology finance policy is to encourage enterprises to engage in more research and development activities through the provision of R&D subsidies and tax incentives. When enterprises opt to capitalize R&D expenses, these costs are treated as assets, thereby presenting a more robust financial condition on the balance sheet. This approach is beneficial in addressing the 'light asset model' issue faced by technology companies and makes financial statements more attractive by displaying higher total assets. For example, the science and technology finance policy mentioned in plans approved by the State Council to support financing for technology enterprises may favor capitalization, as they provide a favorable financial environment for investing in R&D activities and recognizing them as assets. The policy likely leans towards encouraging enterprises to capitalize their R&D expenses, aiming to foster technological innovation and long-term economic growth. However, expensing, being a more conservative accounting approach, may not align with the long-term objectives of these policies, thus the science and technology finance policy may not significantly impact the expensing of R&D expenditures.

Capitalization of R&D investments can more accurately reveal a company's long-term investment intentions and enhance its investment efficiency. Through the capitalization mechanism, firms can amortize R&D investments, thereby more accurately reflecting their contribution to future profitability. This provides both enterprises and investors with a more precise dimension for assessing investment returns. On this basis, companies can more accurately predict future cash flows and profitability, leading to more prudent long-term investment decisions. Furthermore, the capitalization of R&D investments may incentivize companies to increase their spending in research and development, thereby spurring innovation and enhancing competitiveness. Such innovations could lead to new products and services, ultimately improving market share and investment returns.

Table 7. Research and Development Mechanism Analysis

VARIABLES	(1) rd	(2) rd	(3) rd1	(4) rd1	(5) rd2	(6) rd2
policy	1.2820*** (47.17)	0.4159*** (18.40)	0.0062*** (11.86)	0.0059*** (11.47)	0.0003 (1.06)	0.0003* (1.80)
Size		0.9684*** (96.83)		0.0002 (0.67)		0.0000 (0.03)
Lev		-0.7331*** (-11.15)		-0.0071*** (-4.57)		0.0004 (0.81)
ROA		0.2130 (1.52)		0.0091*** (2.62)		-0.0019* (-1.68)
Growth		-0.0602*** (-3.65)		0.0001 (0.24)		-0.0003** (-2.23)
Board		-0.1497*** (-3.09)		-0.0020* (-1.81)		0.0012*** (3.21)
TobinQ		0.0209*** (3.46)		0.0007*** (4.00)		0.0001** (2.15)
ldbl		-0.0232*** (-6.75)		-0.0002 (-1.48)		-0.0000 (-0.11)
Constant	16.9919*** (1,110.61)	-5.8487*** (-20.60)	0.0138*** (49.29)	0.0002 (0.04)	0.0023*** (13.82)	-0.0027 (-1.34)
Observations	19,900	17,925	7,079	6,438	12,412	11,454
R-squared	0.117		0.025		0.000	
Number of id	3,057	2,888	1,616	1,429	2,799	2,667
Firm FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES

5.4. Heterogeneity Analysis: Ownership Type Variability

State-owned enterprises (SOEs) and non-state-owned enterprises (non-SOEs) exhibit distinct differences in their operational objectives and corporate governance due to the nature of their property rights. This study categorizes the sample into two groups based on the nature of corporate ownership: SOEs and non-SOEs, conducting separate regressions for each. The regression results reveal that for the group of SOEs, the coefficient of the science and technology finance policy is not significant. However, for the non-SOEs group, the coefficient is significantly negative. This indicates that the science and technology finance policy does not significantly enhance the investment efficiency of SOEs, but it does improve the investment efficiency of non-SOEs.

The structure and nature of SOEs, coupled with the level of government intervention, may result in a different impact of science and technology finance policies on investment efficiency compared to non-SOEs. SOEs often face higher levels of government intervention, which may manifest as policy burdens. Such intervention can lead to a decrease in operational efficiency in SOEs compared to non-SOEs (Jiang et al., 2021). Transitioning SOEs towards more market-oriented stages is crucial, as the relationship between the government and enterprises is a key factor affecting economic reforms and development. Policy burdens are considered a primary form of government intervention in enterprises.

Science and technology finance policies significantly impact the investment efficiency of non-SOEs through promoting resource allocation efficiency, increasing the number of bank branches, advancing financial technology development, and fostering deep integration of finance and technology. The Financial Research Institute indicates that an increase in the number of bank branches significantly enhances the investment level and efficiency of enterprises. This effect is primarily observed in under-investing enterprises and non-SOEs enterprises, as the proliferation of bank branches can reduce financing constraints and agency conflicts, thereby improving investment efficiency.

Table 8. Ownership Type Variability Analysis

VARIABLES	SOEs		non-SOEs	
	(1) eff	(2) eff	(3) eff	(4) eff
policy	-0.0009 (-1.01)	0.0009 (0.90)	-0.0049*** (-7.24)	-0.0033*** (-4.32)
Size		-0.0041*** (-8.65)		-0.0035*** (-9.50)
Lev		0.0188*** (5.64)		0.0221*** (8.38)
ROA		0.0126* (1.79)		0.0449*** (6.89)
Growth		0.0020** (2.08)		0.0012* (1.74)
Board		-0.0022 (-0.95)		0.0007 (0.36)
TobinQ		-0.0012*** (-4.16)		-0.0006* (-1.76)
ldbl		-0.0001 (-0.57)		-0.0003 (-1.43)
Constant	0.0336*** (41.23)		0.0385*** (63.50)	0.1145*** (12.26)
Observations	7,737	7,570	12,739	12,492
Number of id	1,235	1,234	1,725	1,725
Industry FE	NO	YES	NO	YES
Province FE	NO	YES	NO	YES

SOEs usually have access to direct government aid and subsidies, which might alleviate their financing constraints, thus diminishing the impact of science and technology finance policies on their

investment efficiency (Huang et al., 2021). Consequently, these policies may have a limited effect on the investment efficiency of SOEs. On the other hand, non-SOEs might rely more on external financing to support innovation. Science and technology finance policies, through a series of reform measures such as pilot programs for investment-loan linkage and financial support for the high-tech service industry, can support the innovative activities of these enterprises, thereby enhancing investment efficiency.

5.5. Heterogeneity Analysis: Scale Variability

This study further investigates scale heterogeneity by categorizing the sample into two groups based on enterprise size: large enterprises and small-to-medium enterprises (SMEs), conducting subgroup regressions accordingly. The regression results indicate that for the large enterprise group, the coefficients of the science and technology finance policy are consistently negative and significant at the 1% level. This suggests that the science and technology finance policy can enhance the investment efficiency of large enterprises. However, in the regressions for SMEs, the coefficients of the science and technology finance policy are not significant, indicating that the policy does not have a significant impact on the investment efficiency of SMEs.

Large enterprises typically benefit more readily from science and technology finance policies due to their scale, resources, and market position, whereas SMEs face more challenges and difficulties. In terms of resource acquisition capabilities, large enterprises generally have access to more resources and stronger negotiating power to obtain support and funding under science and technology finance policies. In contrast, SMEs may be relatively weaker in financial and human resources. Science and technology finance policies tend to provide credit support through soft loans, interest subsidies, and guarantees. Due to their size and credibility, large enterprises are more likely to access such credit support, while SMEs may face higher loan rates and stricter loan conditions. In terms of product and service optimization, the analysis could explore how these policies impact the optimization of products and services in large versus SMEs.

Table 9. Scale Variability Analysis

	large enterprises		SMEs.	
VARIABLES	(1) eff	(2) eff	(3) eff	(4) eff
policy	-0.0064*** (-5.37)	-0.0058*** (-4.23)	-0.0031*** (-5.13)	-0.0009 (-1.37)
Size		-0.0025*** (-2.59)		-0.0046*** (-11.34)
Lev		0.0318*** (5.25)		0.0195*** (8.64)
ROA		0.0571*** (3.90)		0.0263*** (5.15)
Growth		0.0038*** (3.27)		0.0007 (1.06)
Board		-0.0001 (-0.05)		-0.0015 (-0.88)
TobinQ		0.0019* (1.67)		-0.0011*** (-5.09)
ldbl		-0.0005 (-0.50)		-0.0003* (-1.93)
Constant	0.0403*** (35.36)	0.0945*** (3.81)	0.0369*** (66.92)	0.1413*** (14.32)
Observations	3,667	3,626	16,809	16,436
Number of id	621	621	2,780	2,778
Industry FE	NO	YES	NO	YES
Province FE	NO	YES	NO	YES

6. Conclusions and Policy Recommendations

Amidst China's economic transformation and rapid technological development, the country has engaged in extensive practices of science and technology finance, profoundly impacting micro-enterprises. Utilizing the 'Promotion of Science and Technology-Finance Integration Pilot' as a quasi-natural experiment, this study constructs a panel dataset of 3,468 non-financial listed companies from 2007 to 2019, employing a progressive DID model to examine the impact and mechanisms of science and technology finance policy on corporate investment efficiency. The study finds that, overall, the implementation of science and technology finance policy significantly enhances corporate investment efficiency. This conclusion remains valid after a series of robustness tests, including parallel trend tests, placebo tests, and PSM-DID. Further mechanism analysis indicates that science and technology finance policy improves investment efficiency by relaxing corporate financing constraints, enhancing the degree of digital transformation, and increasing capitalized R&D in enterprises. Heterogeneity tests reveal significant differences in the policy's impact on enterprises of different ownership types and sizes. Specifically, the implementation of science and technology finance policy has a more pronounced effect on enhancing the investment efficiency of non-state-owned and large enterprises.

To further implement science and technology finance policies, this paper proposes the following three policy recommendations. Firstly, enhance the comprehensive benefits of science and technology finance policies. At the macro level, to maximize the impact of these policies on improving corporate investment efficiency, it is crucial to strengthen inter-departmental coordination and information sharing, and to establish an integrated information-sharing platform to reduce information asymmetry between enterprises and financial institutions. Furthermore, the government should deepen the combination of market-driven resource allocation and governmental regulation, creating a conducive market environment for the growth of high-tech enterprises. This includes policy guidance and financial support to address market shortcomings in encouraging innovative R&D and technology transfer. Simultaneously, establish a comprehensive evaluation system for the effects of science and technology finance policies to monitor and assess the implementation results, allowing timely policy adjustments to ensure efficient resource allocation and effective policy execution.

Secondly, strengthen technological finance support for large private enterprises. To fully leverage the potential of science and technology finance policies in enhancing enterprise investment efficiency, especially for non-state-owned and large enterprises, more targeted support measures should be implemented. Given the significant potential of these types of enterprises in improving investment efficiency, the government should consider providing special support such as tax relief, financing guarantees, and innovation funds to optimize their development environment. These preferential policies can incentivize enterprises to expand R&D investment and reduce the economic risks of innovation activities. Additionally, encourage large enterprises to establish close industry-academia-research cooperation with universities and research institutions. This not only accelerates the transformation of technological achievements but also enhances enterprises' independent innovation capabilities, leading to more original technologies and products with market competitiveness. Through these comprehensive measures, the technological level and international competitiveness of the entire industry can be effectively improved.

Thirdly, science and technology finance policies should particularly focus on promoting enterprise digital transformation. Firstly, improve digital infrastructure. Accelerate the construction of digital infrastructure such as 5G and cloud computing, providing fundamental support for enterprise digital transformation. Simultaneously, encourage and support widespread adoption of digital technologies like cloud computing and big data analytics in enterprises to achieve a digital upgrade of business processes and service models. Support measures for digital transformation could include fiscal subsidies, tax incentives, or technical consulting services, all aimed at helping enterprises more effectively utilize digital tools to enhance operational efficiency and market competitiveness. Additionally, establish special funds to directly invest in enterprise digital transformation through venture capital, compensating for market limitations. In the long run, continuously promoting enterprise digital transformation will be beneficial for the overall transition of China's economy

towards digitalization, networking, and intelligent development, enhancing industrial core competitiveness. This will not only enhance investment efficiency but also foster long-term development and innovation in the digital economy.

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