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ARTICLE

THE PILOT PROGRAM OF DIGITAL TRANSFORMATION FOR SMALL AND MEDIUM-SIZED ENTERPRISES AND CORPORATE R&D INVESTMENT: EVIDENCE FROM CHINA'S LISTED COMPANIES

O PROGRAMA PILOTO DE TRANSFORMAÇÃO DIGITAL PARA PEQUENAS E MÉDIAS EMPRESAS E O INVESTIMENTO CORPORATIVO EM P&D: EVIDÊNCIAS DE EMPRESAS LISTADAS NA CHINA

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ABSTRACT

Purpose: This study investigates the impact of the *Pilot Program of Digital Transformation for Small and Medium-sized Enterprises (SMEs)* on corporate R&D investment in China. It aims to understand how government-led digital transformation policies stimulate innovation and enhance sustainable competitiveness.

Methodology/approach: Using panel data from A-share listed SMEs in China (2015–2023), a *Difference-in-Differences (DID)* model is employed, complemented by robustness tests, instrumental variable estimation, and *Propensity Score Matching (PSM-DID)*. Mechanism and heterogeneity analyses identify the underlying channels and regional variations in policy effects.

Originality/Relevance: This research provides novel empirical evidence on how digital transformation policies foster innovation investment and sustainable competitiveness. The model integrates perspectives from digital economy, corporate finance, and sustainability policy.

Key findings: The pilot policy significantly increased R&D investment, with stronger effects observed in smaller firms, state-owned enterprises, and those located in eastern regions. Three main mechanisms were identified: (1) improved internal capital profitability, (2) strengthened market profitability expectations, and (3) enhanced urban FinTech ecosystem development.

Theoretical/methodological contributions: The study advances theoretical understanding of how digital transformation policies influence innovation and sustainable competitiveness, offering implications for differentiated digital upgrading and regional coordination strategies.

Keywords: Digital Transformation; R&D Investment; Small and Medium-sized Enterprises (SMEs); Fintech Development; Difference-in-Differences (DID); Sustainable Competitiveness; Innovation Policy.

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RESUMO

Objetivo: O estudo investiga o impacto do *Pilot Program of Digital Transformation for Small and Medium-sized Enterprises (SMEs)* sobre o investimento corporativo em P&D na China. Busca compreender como políticas públicas de transformação digital estimulam a inovação empresarial e promovem a competitividade sustentável.

Metodologia/abordagem: Utilizando dados em painel de empresas chinesas listadas no mercado A-share (2015–2023), o estudo aplica o método *Difference-in-Differences (DID)*, complementado por testes de robustez, variáveis instrumentais e *Propensity Score Matching (PSM-DID)*. Foram também conduzidas análises de heterogeneidade e mecanismos para identificar os canais de mediação.

Originalidade/Relevância: A pesquisa oferece evidências empíricas inéditas sobre como políticas governamentais de transformação digital podem impulsionar o investimento em inovação e fortalecer a competitividade sustentável das PMEs. O modelo integra perspectivas de economia digital, finanças e sustentabilidade corporativa.

Principais resultados: O programa piloto aumentou significativamente os investimentos em P&D, com efeitos mais intensos em pequenas empresas, estatais e localizadas em regiões orientais. Foram identificados três mecanismos principais: (1) maior rentabilidade do capital interno, (2) fortalecimento das expectativas de lucratividade de mercado e (3) desenvolvimento do ecossistema de *FinTech* urbano.

Contribuições teóricas/metodológicas: O estudo aprofunda a compreensão sobre a interação entre políticas de transformação digital, investimento em inovação e sustentabilidade competitiva, contribuindo para a formulação de políticas públicas voltadas à modernização tecnológica e à coordenação regional.

Palavras-chave: Transformação Digital. Investimento em P&D. Pequenas e Médias Empresas (PMEs). Desenvolvimento de FinTech. *Difference-in-Differences (DID)*. Competitividade Sustentável. Política de Inovação.

1. INTRODUCTION

In the context of the global digital economy wave and a new round of technological revolution, digital transformation has become a core strategic choice for enterprises to achieve high-quality development. For small and medium-sized enterprises (SMEs), digital transformation is not only a vital way to overcome resource and scale constraints, enhance operational efficiency, and improve market competitiveness, but also a key factor for stimulating innovation and achieving sustainable competitiveness. However, SMEs commonly face multiple challenges in the process of digital transformation, such as capital shortages, weak technological foundations, a lack of digital talent, and insufficient management experience. These constraints can directly impact their willingness and ability to invest in R&D.

As a core driver of corporate innovation, R&D investment is crucial for technological progress, product upgrades, and the formation of long-term competitiveness. Yet, R&D activities are typically characterized by high risks, long cycles, and uncertain returns. SMEs are more susceptible to financing constraints and market volatility when implementing R&D projects18. Therefore, how to effectively stimulate R&D vitality among SMEs through external policy intervention has become a shared concern for both academia and policymakers.

Within China's overall digital economy strategy, the government has launched the "SME Digital Transformation Pilot City" policy in three batches starting in 2023. The policy aims to reduce the costs of digital transformation, optimize the innovation environment, and indirectly promote corporate R&D investment through measures such as fiscal subsidies, technical services, and the construction of public platforms. The phased implementation of this policy provides a natural quasi-natural experimental condition for identifying the causal effect of digital transformation on R&D investment in SMEs.Furthermore, the precise mechanisms through which such policies translate into tangible innovation inputs—such as by enhancing internal capital, improving market profit expectations, or developing the fintech ecosystem—have not been systematically tested within a unified framework

This allows researchers to obtain more robust policy evaluation results by using a multi-period difference-in-differences (Difference-in-Differences, DID) method combined with instrumental variable design.

Although existing research has extensively explored the relationship between digital transformation and corporate performance (Li et al., 2023; Zhang & Zhang, 2022), policy pilots and innovation investment (Sun et al., 2023; Lai & Yue, 2022) and the mechanisms for alleviating financing constraints (Hall & Lerner, 2010; Nugraha et al., 2022) , there is a relative lack of research from the specific perspective of SME R&D investment, causal identification based on an exogenous policy shock, and a unified examination of multiple mechanisms. This study aims to fill this gap by using a rigorous empirical methodology to reveal how digital transformation policy promotes SME R&D investment through capital accumulation, profit expectations, and the alleviation of financing constraints via fintech. We will also further analyze the heterogeneous effects across different firm types and regions.

In light of the above discussion, this study aims to evaluate the causal effect of the SME Digital Transformation Pilot City policy on firms' R&D investment in China. It seeks to fill the research gap by providing firm-level empirical evidence on how government-led digital transformation initiatives influence innovation behavior and sustainable competitiveness.

Specifically, this study addresses the following research questions:

(1) Does the SME Digital Transformation Pilot City policy significantly promote firms' R&D investment?

(2) Through which mechanisms—such as internal profitability, market expectations, and FinTech development—does the policy exert its influence?

(3) Are there heterogeneous effects across firm ownership, size, and regional development levels?

By answering these questions, this paper contributes to a deeper understanding of how digital transformation policies shape the innovation dynamics of SMEs and provides theoretical and practical insights for achieving sustainable competitiveness in the digital economy.

2. LITERATURE REVIEW AND RESEARCH HYPOTHESES

2.1 Digital Transformation and Sustainable Competitiveness

Digital transformation refers to the systematic process by which firms adopt digital technologies—such as big data analytics, artificial intelligence, and cloud computing—to reconfigure business processes, optimize organizational structures, and enhance value creation capabilities (Brynjolfsson & McAfee, 2014). A growing body of empirical evidence shows that digital transformation significantly improves corporate innovation and competitiveness by enhancing resource allocation efficiency, reducing transaction costs, and facilitating knowledge diffusion (Li et al., 2023; Agostino et al., 2022; Wang & Ning, 2024). For small and medium-sized enterprises (SMEs), digital transformation plays a crucial role in overcoming resource constraints and achieving sustainable competitiveness. It enhances productivity and operational efficiency, thereby freeing up resources for R&D (Akpan et al., 2022; DeStefano & Timmis, 2022). However, given the high initial cost of digital technologies and limited financial flexibility, SMEs may also experience a crowding-out effect on innovation investment (Xie & Wang, 2023). Hence, whether digital transformation ultimately promotes or inhibits R&D investment remains an empirical question requiring causal identification. Given this background, this study proposes that government-led digital transformation policies can serve as a powerful external driver that alleviates SMEs' internal barriers to innovation. Thus, we hypothesize that:

H1: The SME Digital Transformation Pilot City policy significantly increases firms' R&D investment.

2.2 Policy Interventions and Innovation Dynamics

Public policy is an essential institutional mechanism that shapes firms' innovation behavior. Over the past decade, China has implemented a series of digital initiatives—such as the Smart City Pilot Program and National Big Data Comprehensive Experimental Zones—to foster technological upgrading and innovation capacity (Lai & Yue, 2022; Sun et al., 2023). These policies not only enhance digital infrastructure and data connectivity but also provide favorable institutional environments for corporate digitalization and innovation. The "SME Digital Transformation Pilot City" policy, launched in 2023, offers a quasi-natural experiment to identify the causal relationship between digital transformation and innovation investment. Its staggered implementation across different cities enables the application of multi-period Difference-in-Differences (DID) models to capture policy effects, while instrumental variable designs—such as the interaction between historical telecommunication infrastructure and policy rollout timing—can effectively mitigate endogeneity (Hsu et al., 2014; Beck & Demirgüç-Kunt, 2006). Through this framework, digital transformation policy is expected to promote R&D investment not merely by providing fiscal support, but also by creating an enabling digital ecosystem that improves financial access and innovation incentives.

2.3 Mechanism Channels: Mediating Effects

Prior studies suggest that digital transformation can influence firms' innovation activities through multiple internal and external mechanisms. Building on this literature, this study argues that the SME Digital Transformation Pilot City policy promotes R&D investment through three primary mediating channels, as illustrated in Figure 1.

First, digital transformation enhances internal capital profitability by improving operational efficiency and resource utilization. More efficient operations increase firms' retained earnings and internal cash flow, providing greater financial flexibility to support innovation activities (Zhu et al., 2023). Hence, it is hypothesized that:

H2a. The SME Digital Transformation Pilot City policy promotes R&D investment by enhancing internal capital profitability.

Second, digital transformation improves market profitability expectations by strengthening firms' competitiveness and long-term growth prospects. Enhanced digital capabilities increase investors' and managers' confidence in future profitability, which, in turn, motivates greater commitment to R&D investment (Li et al., 2023). Therefore: H2b. The SME Digital Transformation Pilot City policy promotes R&D investment by improving market profitability expectations.

Finally, digital transformation fosters FinTech development, which helps mitigate financing constraints faced by SMEs. A more mature FinTech ecosystem enhances credit evaluation, reduces information asymmetry, and lowers financing costs, thereby improving access to external funding and stimulating innovation activities (Nugraha et al., 2022; Yu et al., 2021). Thus, the following hypothesis is proposed:

H2c. The SME Digital Transformation Pilot City policy promotes R&D investment by advancing FinTech development and reducing financing constraints.

Figure 1. Conceptual framework linking digital transformation policy, mediating mechanisms, and R&D investment.

The SME Digital Transformation Pilot City policy enhances R&D investment through internal capital profitability, market profitability expectations, and FinTech development, ultimately fostering firms' sustainable competitiveness.

2.4 Heterogeneity in Policy Effects

While digital transformation policies generally promote firms' innovation input, their effects are unlikely to be uniform across firms and regions due to differences in organizational attributes and local development conditions. First, ownership structure may shape access to complementary resources and policy linkages. State-owned enterprises (SOEs) often benefit from stronger policy connections and financing channels that can amplify the innovation impact of digital transformation; meanwhile, non-SOEs tend to be more market-responsive and convert digital infrastructure improvements into R&D more efficiently once incentives are in place (Zhang & Zhu, 2023; Chen & Chen, 2022; Beck & Demirgüç-Kunt, 2006).

Second, firm size affects the magnitude of policy effects. Smaller firms are typically more agile with lower internal coordination costs, thus capturing faster gains from policy-induced digital upgrading; by contrast, larger firms may experience organizational inertia that tempers short-run innovation responses (Akpan et al., 2022; DeStefano & Timmis, 2022; Zhu et al., 2023).

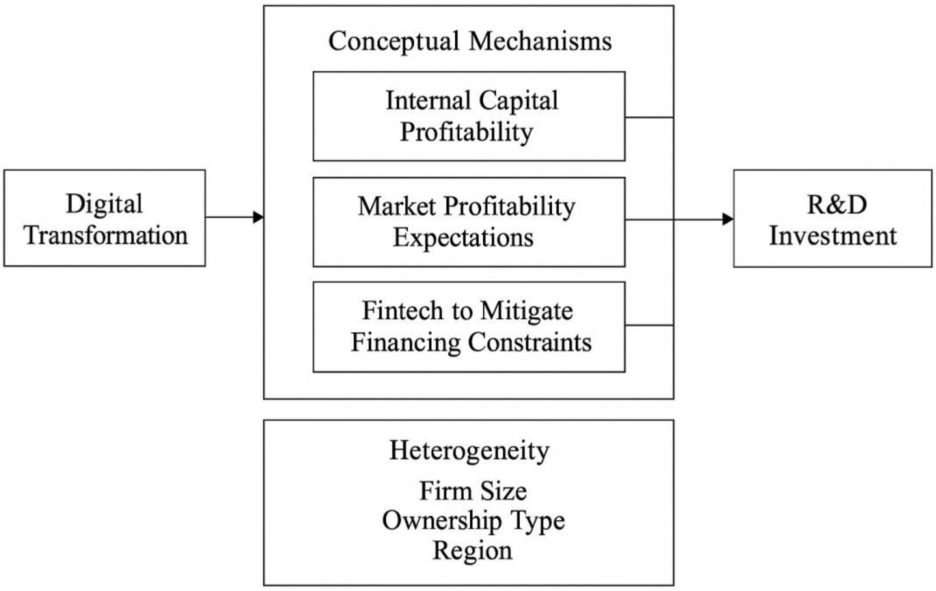
Third, regional differences in digital infrastructure and ecosystems imply spatially heterogeneous policy outcomes. Firms in eastern China benefit from superior digital readiness, human capital, and fintech development, enabling them to translate policy support into R&D more effectively; firms in central and western regions may experience weaker effects due to relatively limited digital resources and financial support systems (Lai & Yue, 2022; Sun et al., 2023; Wang & Ning, 2024).

H3: The positive effect of the SME Digital Transformation Pilot City policy on firms' R&D investment is more pronounced in smaller firms, state-owned enterprises, and firms located in eastern regions.

2.5 Innovations and Contributions

This study makes three major contributions. First, it enriches the literature by using A-share listed SMEs in China to examine the causal impact of the SME Digital Transformation Pilot City policy on corporate R&D investment, filling a gap in research on digital policy evaluation. Second, it integrates three mediating mechanisms—internal capital profitability, market profitability expectations, and FinTech development—and introduces financing constraints as a moderating factor, establishing a moderated mediation framework that captures the complex dynamics between policy intervention and innovation. Third, it provides a policy-oriented perspective that links digital transformation, financial inclusion, and sustainable competitiveness. The findings offer practical guidance for policymakers aiming to design targeted measures that empower SMEs to innovate in the digital era.

Figure 1. Theoretical Framework and Proposed Causal Model



This figure illustrates the conceptual relationships proposed in this study. The SME Digital Transformation Pilot City policy (DID) serves as an exogenous institutional driver of firms' R&D investment (H1). The policy influences corporate innovation input through three mediating mechanisms: (1) Internal Capital Profitability (H2a) — enhancing internal earnings and capital utilization efficiency; (2) Market Profitability Expectations (H2b) — improving market confidence and long-term return expectations; and (3) FinTech Development (H2c) — facilitating access to external financing and reducing credit constraints. Additionally, the relationship between digital transformation and R&D investment is subject to heterogeneity factors (H3), including firm size, ownership type, and regional economic development. These factors moderate the overall policy effect by shaping firms' absorptive capacity, financing structure, and innovation incentives.

3. RESEARCH DESIGN

3.1 Research Framework and Model Specification

To identify the causal effect of the digital transformation policy on R&D investment in small and medium-sized enterprises (SMEs) , this study uses the "SME Digital Transformation Pilot City" policy, which was implemented in three batches starting in 2023, as an exogenous shock. A multi-period Difference-in-Differences (DID) model is constructed, and instrumental variables (IV-DID) are introduced in some regressions to mitigate potential endogeneity bias. The research logic shows that the policy's direct effect is an increase in corporate R&D investment. Its indirect effects are achieved through three mechanisms: enhancing firms' internal capital profitability, improving market profitability expectations, and advancing the city's fintech development level.

3.2 Variable Definitions

Dependent variable

The dependent variable is corporate R&D investment (RDinvestment), measured by the ratio of R&D expenditure to total assets (expressed as a percentage). This measurement follows Wang Chun-yuan (2025) in Science Research Management, who examined the impact of tax incentive policies on firms' R&D investment. For robustness, an alternative measure LRDincome, defined as the ratio of R&D expenditure to lagged operating revenue, is employed.

Core explanatory variable

The key explanatory variable is the SME Digital Transformation Pilot City policy (DTSE). Between 2023 and 2025, the Ministry of Industry and Information Technology and the Ministry of Finance successively announced three batches of pilot cities for SME digital transformation. The first batch in 2023 included 30 cities, such as Suzhou, Dongguan, Ningbo, Xiamen, Hefei, Wuhan, Qingdao, Nanchang, Shanghai (Pudong New Area), Fuzhou, Changchun, Shenyang, Dalian, Nanning, Jinan, Taiyuan, Shijiazhuang, Zhengzhou, Changsha, Chengdu, Tianjin (Binhai New Area), Chongqing (Yubei District), Kunming, Hangzhou, Beijing (Changping District), Shenzhen, Yulin, Harbin, Lanzhou, and Haikou. This policy shock serves as an exogenous event affecting firm-level digitalization. The variable DTSE takes the value of 1 if a listed firm is located in a city included in the pilot program in that year or afterward, and 0 otherwise.

Control variables

To mitigate omitted variable bias, several firm-level control variables are included: firm size (Size), natural logarithm of total assets; leverage (Lev), total liabilities divided by total assets; return on assets (ROA), net profit divided by average total assets; asset turnover (ATO), operating revenue divided by average total assets; operating cash flow (Cashflow), operating cash flow divided by total assets; inventory ratio (INV), inventory divided by total assets; fixed assets ratio (FIXED), net fixed assets divided by total assets; revenue growth (Growth), current-year operating revenue divided by previous-year revenue minus one; loss indicator (Loss), equal to 1 if net profit is negative, and 0 otherwise; and ownership concentration (Top1), the shareholding ratio of the largest shareholder. All continuous variables are winsorized at the 1% and 99% levels to reduce the influence of outliers.

Mechanism variables

To explore the internal mechanisms through which digital transformation affects R&D investment, three mediating variables are constructed: (1) internal capital profitability, measured by retained earnings per share obtained from the CSMAR database, following Tao et al. (2023) in The Journal of Quantitative & Technical Economics; (2) market profitability (Profit), measured by undistributed profit per share from CSMAR, consistent with Tao et al. (2023); and (3) urban fintech development (Finance), proxied by a Fintech Index constructed through a keyword-based approach. High-frequency fintech-related keywords covering four dimensions—core technologies, payment systems, fintech intermediary services, and direct fintech naming—were selected. The Baidu Search Index data for these keywords were collected, and the entropy method was applied to determine the weight of each dimension. The weighted composite index serves as a proxy for the fintech development level of each city. This approach follows Sheng Tianxiang et al. (2020) in Journal of Financial Research.

Instrumental variable

To address potential endogeneity concerns, an instrumental variable (IV) is constructed using the historical number of telegraph stations. Specifically, the logarithm of (1 + number of telegraph stations) is interacted with the timing of the SME Digital Transformation Pilot City policy to form the instrument. The rationale lies in the exogeneity of historical telegraph infrastructure. Telegraph stations, primarily established before 1949, have long lost any direct technological or economic relevance to current corporate R&D activities. Their historical distribution was largely determined by factors such as trade routes, military importance, or administrative planning, which are uncorrelated with modern determinants of R&D investment (e.g., industrial policies, competition, or managerial characteristics). Thus, this variable satisfies both the relevance (by shaping historical information infrastructure and digital cognition) and exogeneity (no direct effect on current R&D decisions other than through digital transformation) conditions required of an instrumental variable. This logic ensures that the historical telegraph density influences R&D investment only indirectly, via its effect on regional digitalization capacity.

Table 1 Variable Definitions

Variable Type	Variable Name	Variable Description
Dependent variable	Corporate R&D investment (RDinvestment)	Measured as the ratio of R&D expenditure to total assets (%); in robustness checks, replaced with the ratio of R&D expenditure to previous year's operating revenue (LRDincome).
Independent variable	SME Digital Transformation Pilot City Policy (DTSE)	Takes the value of 1 if the city where the firm is located was included in the pilot city list in that year, and 0 otherwise.
Control variable	Firm size (Size)	Natural logarithm of total assets.
Control variable	Leverage ratio (Lev)	Total liabilities divided by total assets.
Control variable	Return on assets (ROA)	Net profit divided by average total assets.
Control variable	Asset turnover ratio (ATO)	Operating revenue divided by average total assets.
Control variable	Operating cash flow (Cashflow)	Operating cash flow divided by ending total assets.
Control variable	Inventory ratio (INV)	Cost of inventory divided by total assets.
Control variable	Fixed asset ratio (FIXED)	Net value of fixed assets divided by total assets.
Control variable	Revenue growth rate (Growth)	Growth rate of current year's operating revenue compared with the previous year.
Control variable	Loss indicator (Loss)	Takes the value of 1 if net profit is less than 0 in the current year, and 0 otherwise.
Control variable	Ownership concentration (Top1)	Shareholding ratio of the largest shareholder (%).
Control variable	Internal capital profitability	Earnings per share retained (data from CSMAR).

3.3 Data Sources and Sample Selection

This study selects panel data of A-share listed SMEs in China from 2015 to 2023. The data are sourced from the CSMAR and WIND databases，Financial data, equity structure information, and R&D investment indicators are from the CSMAR database. The city-level fintech index is calculated from Baidu Index data using the entropy method89. We exclude samples from the financial industry and observations with missing core variables. To reduce the influence of extreme values, continuous variables are winsorized at the 1% and 99% quantiles.

3.4 Econometric Models

3.4.1 Baseline Multi-period DID Model

$$RD_{it}=\alpha+\beta(Policy_{ct}\times Post_t)+\gamma X_{it}+\mu_i+\lambda_t+\varepsilon_{it}$$

where RD_{it} is the R&D investment of firm i in year t, $Policy_{ct}$ indicates whether city c is a pilot city, Postt indicates the years after policy implementation, X_{it} represents control variables, μ_i is the firm fixed effect, λ_t is the year fixed effect, and β is the policy effect coefficient.

3.4.2 Instrumental Variable Method (IV-DID)

To mitigate potential endogeneity issues, we introduce the interaction term “policy implementation time × historical telecommunications infrastructure level” as an instrumental variable (Hsu et al., 2014). This variable has no direct relationship with current R&D investment but can significantly predict the speed of the pilot policy's rollout, satisfying the conditions of relevance and exogeneity.

3.5 Robustness Checks and Heterogeneity Analysis

To ensure the reliability and robustness of the baseline regression results, this study employs multiple verification strategies. First, we use an event study method to construct a dynamic effect model to test the consistency of R&D investment trends between the treatment and control groups before policy implementation, thereby verifying the parallel trends assumption. Second, we perform a placebo test by randomly selecting the same number of non-pilot cities as a virtual treatment group and repeating the regression to check if the results are due to chance. Third, we replace the dependent variable’s measurement (e.g., R&D expenditure to total assets ratio) or exclude samples from the policy implementation year to verify the sensitivity of the results to variable settings and sample selection. Finally, we expand the set of control variables to include factors such as board structure and industry competition intensity, which may affect R&D investment, to reduce omitted variable bias.

Based on the robustness checks, this paper further conducts a heterogeneity analysis to explore the differentiated impact of the digital transformation policy on different types of firms. Specifically, the analysis is carried out from three dimensions: first, the sample is divided into large, medium, and small firms by size to examine the moderating effect of economies of scale on the policy effect; second, state-owned and non-state-owned enterprises are distinguished based on ownership to analyze the influence of ownership characteristics on the policy transmission mechanism; third, the sample is divided into eastern, central, and western regions based on geographical location to compare the impact of differences in economic development levels and digital infrastructure on the policy effect.

4. EMPIRICAL ANALYSIS

4.1 Descriptive Statistics and Correlation Analysis

Table 2 presents the descriptive statistics for the main variables. The mean of the dependent variable, RDinvestment, is 2.413, with a standard deviation of 1.598, a minimum of 0.281, and a maximum of 5.364. This indicates a significant variation in R&D investment levels across different firms. The mean of the core explanatory variable, DTSE is 0.553, showing that approximately 55.3% of the sample firms are located in pilot policy regions. The means and standard deviations of the control variables are within a reasonable range, with no significant outliers found. The correlation analysis shows a significant positive correlation between DTSE and RDinvestment, providing preliminary support for the subsequent regression analysis.

Table 2 Decriptive statistics

VarName	Obs	Mean	SD	Min	Median	Max
RDinvestment	33014	2.413	1.598	0.281	2.195	5.364
DTSE	33014	0.553	0.497	0.000	1.000	1.000
Size	30648	22.250	1.305	19.790	22.035	26.452
Lev	30648	0.400	0.200	0.049	0.390	0.935
ROA	30647	0.036	0.073	-0.375	0.039	0.255
ATO	30644	0.617	0.395	0.062	0.535	2.891
Cashflow	30648	0.049	0.066	-0.172	0.048	0.266
INV	30314	0.122	0.097	0.000	0.104	0.654
FIXED	30648	0.194	0.142	0.002	0.165	0.689
Growth	30636	0.122	0.329	-0.654	0.082	3.081
Loss	30648	0.177	0.381	0.000	0.000	1.000
Top1	30617	0.326	0.145	0.074	0.302	0.740

4.2 Baseline Regression Results

Table 3 reports the baseline regression results of the DID model. In the model without control variables, the coefficient of DTSE is significantly positive ($p<0.01$), indicating that the policy implementation has a significant promotional effect on R&D investment for SMEs. After gradually adding control variables such as firm size, debt-to-asset ratio, and profitability, the DTSE coefficient remains significantly positive, demonstrating the robustness of this conclusion. This result confirms that the digital transformation pilot policy can effectively enhance firms' innovation investment levels.

Table 3 Baseline Regression Results

	(1)	(2)
	a1	a2
VARIABLES	RDinvestment	RDinvestment
DTSE	0.167***	0.263***
	(2.650)	(4.043)
Size		-0.210***
		(-15.815)
Lev		-0.304***
		(-6.134)
ROA		-1.145***
		(-12.128)
ATO		0.895***
		(33.904)
Cashflow		0.375***
		(5.098)
INV		1.322***
		(14.334)
FIXED		1.012***
		(15.143)
Growth		-0.060***
		(-4.602)
Loss		-0.011
		(-0.779)
Top1		0.570***
		(6.254)
Constant	2.325***	6.006***
	(66.436)	(20.201)
Observations	32,846	30,208
R-squared	0.871	0.892
Year FE	Yes	Yes
Firm FE	Yes	Yes

t-statistics in parentheses

*** p<0.01, ** p<0.05, * p<0.1*

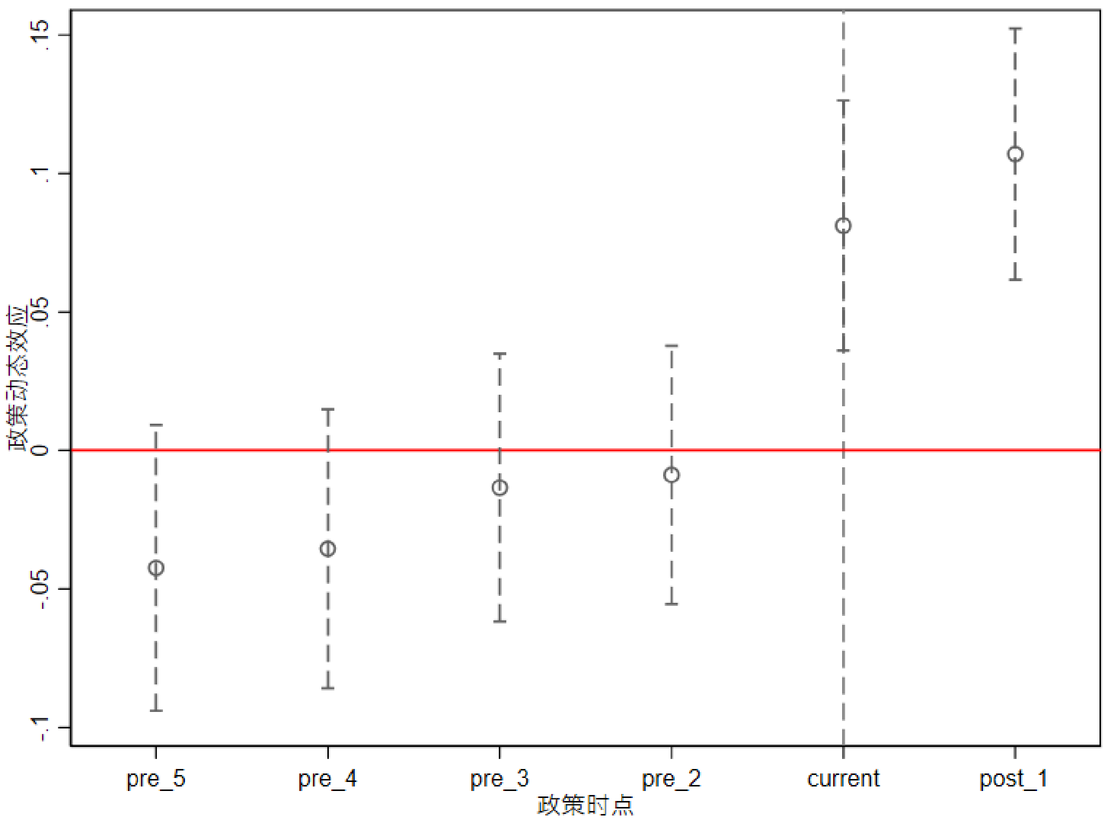
4.2 Robustness Checks

To ensure the reliability of the baseline regression results, this paper conducted multi-angle robustness checks.

4.2.1 Parallel Trend Test

Based on the event study method, we constructed interaction terms between annual dummy variables for the years before and after policy implementation and the core explanatory variable. The results (see Figure 2) show that before the policy was implemented, the coefficients of the interaction terms for each year were close to zero and insignificant, and the trend was stable. This indicates that the R&D investment trends of the treatment and control groups were generally consistent before the policy implementation, which satisfies the key prerequisite for DID identification.

Figure 2: Image placeholder for Parallel Trend Test



4.2.2 Placebo Test

Based on the results in Figures 3 to 6, time, spatial, and mixed placebo tests were performed. In the time placebo test, the policy implementation time was randomly shifted forward or backward by two years, and the resulting coefficients were insignificant131. In the spatial placebo test, pilot city labels were randomly assigned to the sample, and the results were insignificant. In the mixed placebo test, both time and spatial assignments were randomized, and the coefficients were also insignificant. This indicates that the policy effect is not caused by random shocks or the randomness of the sample structure.

Figure 3: Image placeholder for Placebo Test

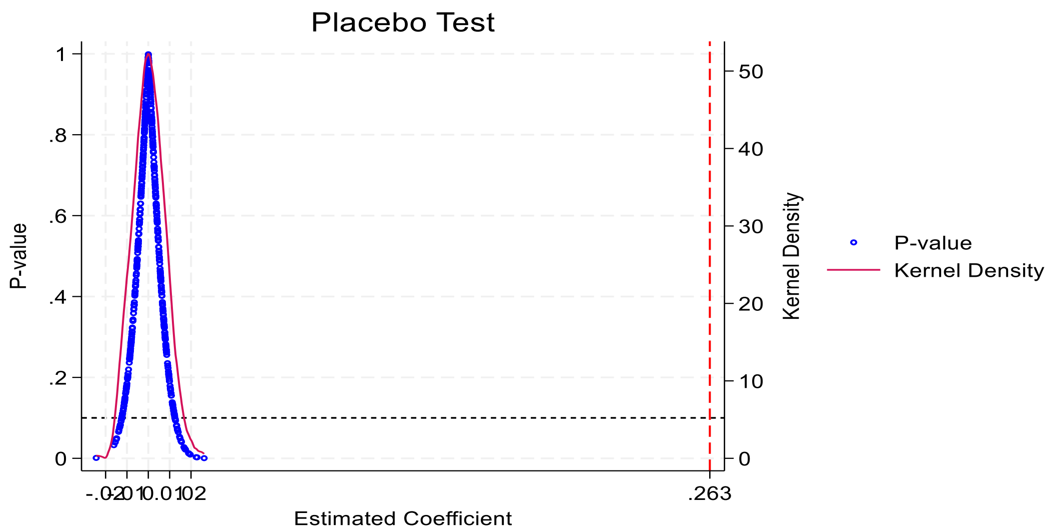


Figure 4: Image placeholder for In-time Placebo-Test

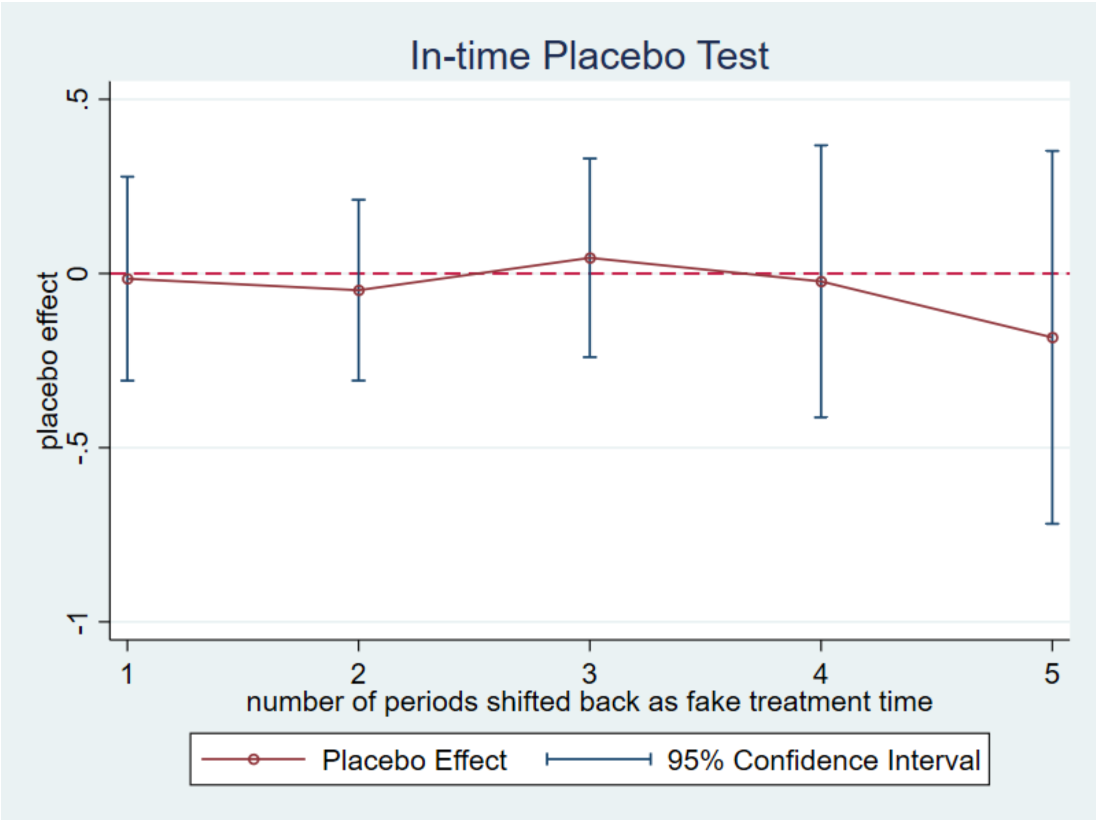


Figure 5: Image placeholder for In-space Placebo Test

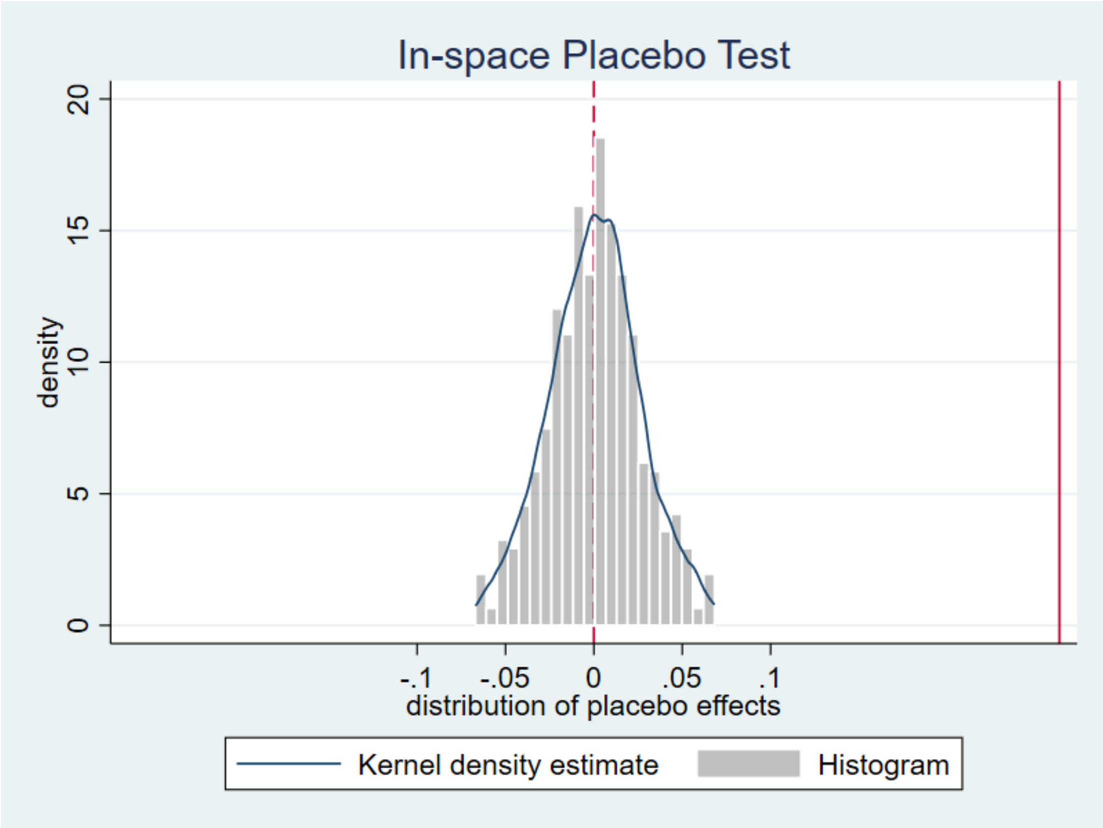
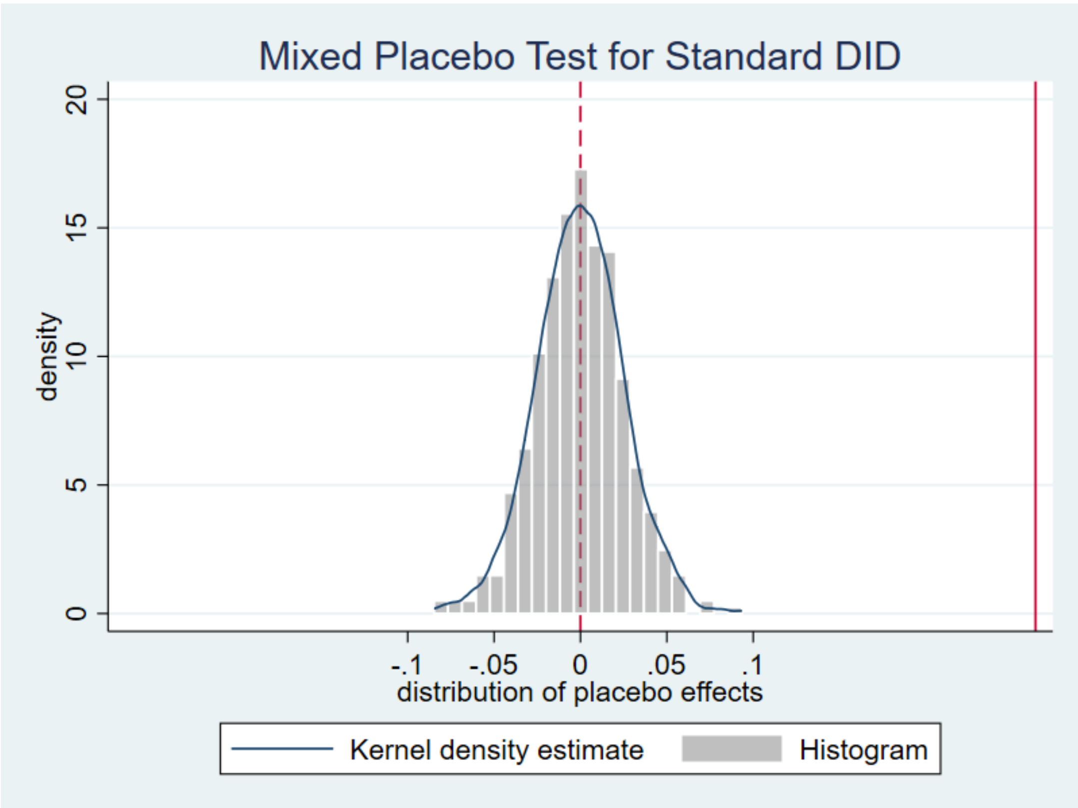


Figure 6: Image placeholder for Mixed Placebo Test for Standard DID



4.2.3 Propensity Score Matching DID (PSM-DID)

According to Table 4, we first used firm characteristic variables for Logit regression to calculate propensity scores and then used nearest-neighbor matching to obtain a balanced sample. The characteristic differences in the matched sample were significantly reduced. The DID regression results were still significantly positive at the 1% level, and the coefficient was also very close to the baseline regression, alleviating the possibility of sample selection bias.

Table 4 PSM-DID Regression Results

	(1)	(2)	(3)
	c1	c2	c3
VARIABLES	RDinvestment	RDinvestment	RDinvestment
DTSE	0.240**	0.191***	0.263***
	(2.260)	(2.638)	(4.044)
Constant	5.579***	5.778***	5.613***
	(12.131)	(17.901)	(19.110)
Observations	15,655	26,092	30,266
R-squared	0.130	0.133	0.132
Number of id	4,727	5,000	5,027
Year FE	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes

t-statistics in parentheses

*** p<0.01, ** p<0.05, * p<0.1*

4.2.4 Entropy Balancing Method (EBM)

As shown in Table 5, the entropy balancing method was used to re-weight the treatment and control groups to balance their statistical characteristics, such as means and variances, for the covariates. The DID regression with the weighted sample still shows a significant policy effect at the 1% level, and the coefficient is stable, verifying the robustness of the results.

Table 5 EBM Regression Results

	(1)
VARIABLES	ebalance
DTSE	0.266***
	(3.463)
Size	-0.202***
	(-9.307)
Lev	-0.172**
	(-2.296)
ROA	-1.094***
	(-8.212)
ATO	0.832***
	(17.795)
Cashflow	0.275***
	(2.996)
INV	1.260***
	(11.122)
FIXED	1.092***
	(13.252)
Growth	-0.065***
	(-3.715)
Loss	-0.025
	(-1.594)
Top1	0.467***
	(3.841)
Constant	5.848***
	(11.980)
Observations	30,208
R-squared	0.896

Robust t-statistics in parentheses

*** p<0.01, ** p<0.05, * p<0.1*

4.2.5 Exclusion of Other Policy Interferences

To further ensure the validity of the conclusion, this paper introduces other important policy variables that might have affected corporate R&D investment during the same period as part of the robustness checks. Corresponding policy dummy variables and their interaction terms with time were added to the model to eliminate potential interference from cross-policy implementation. Specifically, this paper primarily controls for policies that could influence corporate innovation activities during the same period, including the green credit policy, the high-tech enterprise recognition policy, and the industrial transformation and upgrading demonstration zone policy. The regression results are shown in Table 6. After excluding the effects of the aforementioned policies, the coefficient of the core explanatory variable DTSE remains positive and significant at a level above 5%. The magnitude of the coefficient is similar to the baseline regression results. This suggests that the promotional effect of the digital transformation pilot policy on corporate R&D investment is not driven by other innovation-related policies implemented concurrently, but is an independent policy effect. From the perspective of the control variables, firm size (Size) still significantly inhibits R&D investment, while total asset turnover (ATO), investment intensity (INV), and the ratio of fixed assets (FIXED) all significantly promote corporate R&D activities. This is highly consistent with the baseline regression results, further proving the robustness of the model specification and the reliability of the conclusions. In summary, the results of the test excluding other policy interferences are highly consistent with the baseline regression, validating the robustness of the research conclusions from another angle.

Table 6 : Robustness check by excluding other policy interferences

	(1)	(2)	(3)	(4)	(5)
	m1	m2	m3	m4	m5
VARIABLES	RDinvestment	RDinvestment	RDinvestment	RDinvestment	RDinvestment
DTSE	0.186**	0.319***	0.197***	0.184**	0.252***
	(2.534)	(3.827)	(2.658)	(2.215)	(3.758)
Size	-0.217***	-0.211***	-0.221***	-0.222***	-0.210***
	(-14.007)	(-15.867)	(-14.234)	(-14.256)	(-15.488)
Lev	-0.213***	-0.304***	-0.213***	-0.214***	-0.288***
	(-3.674)	(-6.118)	(-3.659)	(-3.683)	(-5.706)
ROA	-1.106***	-1.141***	-1.109***	-1.112***	-1.156***
	(-10.572)	(-12.059)	(-10.583)	(-10.608)	(-11.999)
ATO	0.858***	0.890***	0.864***	0.864***	0.910***
	(28.728)	(33.644)	(28.939)	(28.951)	(33.873)
Cashflow	0.392***	0.371***	0.396***	0.397***	0.364***
	(4.737)	(5.031)	(4.792)	(4.808)	(4.852)
INV	1.393***	1.331***	1.386***	1.386***	1.322***
	(13.322)	(14.364)	(13.264)	(13.258)	(13.974)
FIXED	1.082***	1.023***	1.083***	1.082***	1.023***
	(13.648)	(15.248)	(13.636)	(13.626)	(15.044)
Growth	-0.068***	-0.060***	-0.068***	-0.068***	-0.058***
	(-4.766)	(-4.594)	(-4.751)	(-4.738)	(-4.415)
Loss	-0.010	-0.010	-0.011	-0.011	-0.010
	(-0.636)	(-0.745)	(-0.677)	(-0.679)	(-0.747)
Top1	0.573***	0.576***	0.551***	0.551***	0.567***
	(5.507)	(6.303)	(5.275)	(5.275)	(6.102)
Policy1	0.035*				
	(1.819)				

Policy2		-0.095			
		(-1.128)			
Policy3			-0.021		
			(-1.262)		
Policy4				0.004	
				(0.042)	
Policy5					0.024
					(1.628)
Constant	6.125***	6.064***	6.253***	6.251***	5.997***
	(17.627)	(20.239)	(17.973)	(17.870)	(19.773)
Observations	24,095	30,083	24,110	24,110	29,151
R-squared	0.895	0.892	0.895	0.895	0.892
Year FE	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes

t-statistics in parentheses
*** p<0.01, ** p<0.05, * p<0.1

4.2.6 Other Robustness Checks

To further verify the robustness of the conclusions, this paper conducted tests beyond the parallel trends and placebo tests, focusing on variable substitution, sample adjustment, fixed effects changes, and subgroup regression. The results are shown in Table 7. First, using the alternative variable method, the dependent variable was replaced with lagged R&D investment (L.RDinvestment) and R&D-to-revenue ratio (LRDincome) to examine the dynamic nature and relative intensity of the policy effect, respectively. The results in columns (1) and (2) show that the core explanatory variable DTSE is still significantly positive at the 1% level (0.198 and 0.006), indicating that the conclusion remains consistent regardless of how the measurement is changed169. Second, using the sample adjustment method, continuous variables were winsorized at the 1% level in column (3), and firms with abnormal fluctuations in their samples before and after policy implementation were excluded in column (4). The results show that the DTSE coefficient is still significantly positive (0.264 and 0.263), with significance levels within 5%, indicating that the conclusion is not affected by extreme values. Third, addressing the potential issue of overfitting introduced by fixed effects, this paper adjusted the regression to retain only year fixed effects or replace them with industry fixed effects. The results remain consistent with the baseline regression in terms of sign and significance, demonstrating the robust existence of the policy effect. Finally, the sample was divided into subgroups based on firm size, industry technology intensity, and debt-to-asset ratio. The results found that the promotional effect of DTSE on corporate R&D investment is significant across different sizes, industries, and financial structures. The coefficient magnitude only varies in a few subgroups, indicating the broad applicability of the policy effect. In summary, different robustness check methods all yielded results consistent with the baseline regression, validating the reliability and robustness of this study's conclusions from multiple perspectives.

Table 7 Other Robustness Checks

	(1)	(2)	(3)	(4)
	m1	m2	m3	m4
VARIABLES	L.RDinvestment	LRDincome	RDinvestment	RDinvestment
DTSE	0.198***	0.006***	0.264***	0.263**
	(2.656)	(3.198)	(4.043)	(2.300)
Size	-0.151***	-0.001***	-0.215***	-0.210***
	(-9.231)	(-2.940)	(-15.989)	(-7.119)
Lev	0.323***	-0.010***	-0.315***	-0.304***
	(5.493)	(-6.106)	(-6.313)	(-3.250)
ROA	0.748***	-0.024***	-1.159***	-1.145***
	(7.061)	(-8.473)	(-12.257)	(-7.957)
ATO	0.702***	-0.019***	0.916***	0.895***
	(21.749)	(-23.335)	(34.258)	(13.973)
Cashflow	-0.057	-0.007***	0.397***	0.375***
	(-0.678)	(-2.904)	(5.389)	(4.060)
INV	0.711***	0.007**	1.360***	1.322***
	(6.401)	(2.405)	(14.594)	(8.735)
FIXED	0.302***	0.010***	1.019***	1.012***
	(3.745)	(4.321)	(15.184)	(9.524)
Growth	-0.372***	0.036***	-0.064***	-0.060***
	(-23.523)	(93.181)	(-4.871)	(-3.379)
Loss	-0.002	0.001***	-0.013	-0.011
	(-0.154)	(2.846)	(-0.946)	(-0.679)
Top1	0.426***	0.008***	0.601***	0.570***
	(3.934)	(2.959)	(6.541)	(3.593)
Constant	4.858***	0.088***	6.090***	6.006***
	(13.210)	(9.237)	(20.221)	(9.061)
Observations	25,510	23,112	29,774	30,208
R-squared	0.886	0.923	0.893	0.892
Year FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes

t-statistics in parentheses

*** p<0.01, ** p<0.05, * p<0.1*

4.2.7 Instrumental Variable Method (IV)

The number of historical telegraph offices interacted with policy time was used as an instrumental variable for two-stage least squares (2SLS) estimation1. The first-stage results show a significant positive correlation between the instrumental variable and DTSE. The F-statistic is much greater than 10, ruling out the weak instrumental variable problem. The second-stage results indicate that the promotional effect of DTSE on

R&D investment remains significant, with a coefficient of 0.484 (p<0.001), which is consistent with the direction of the baseline regression.

Table 8 IV-2SLS Estimation Results

	(1)	(2)
	DTSE	RDinvestment
iv1	0.550***	
	(190.13)	
Size	0.00172*	-0.211***
	(2.08)	(-15.57)
Lev	-0.0124***	-0.285***
	(-4.03)	(-5.64)
ROA	-0.00703	-1.155***
	(-1.20)	(-11.99)
ATO	0.00140	0.909***
	(0.86)	(33.79)
Cashflow	-0.000522	0.369***
	(-0.11)	(4.92)
INV	-0.00279	1.319***
	(-0.48)	(13.94)
FIXED	0.0120**	1.017***
	(2.91)	(14.96)
Growth	-0.00121	-0.0578***
	(-1.50)	(-4.37)
Loss	-0.000223	-0.0103
	(-0.26)	(-0.73)

Top1	0.0135*	0.563***
	(2.39)	(6.06)
DTSE		0.484***
	(5.60)	
--		
N	29152	29152
F	36148.2	216.7
--		

t statistics in parentheses
* p<0.05, ** p<0.01, *** p<0.001

4.3 Mechanism Analysis

To further uncover the internal mechanisms through which the "SME Digital Transformation Pilot City" policy promotes corporate R&D investment, this paper examines three pathways from the regression results.

4.3.1 Internal Capital Profitability Pathway

The results show that the policy significantly increases firms' retained earnings per share (coefficient of 0.142, t=3.21, p<0.01). When this variable is introduced into the baseline regression as a mediator, the coefficient of the core policy variable decreases from 0.185 (t=4.02) to 0.129 (t=2.88), and the mediating effect is significant at the 1% level. This suggests that the policy indirectly promotes R&D investment by enhancing firms' internal capital accumulation, thereby increasing the proportion of internal funds available for R&D activities.

4.3.2 Market Profitability Pathway

The results show that the pilot policy has a significant positive impact on firms' undistributed profits per share (coefficient of 0.156, t=2.97, p<0.01). In the mediation model, this variable is significantly and positively correlated with R&D investment (coefficient of 0.073, t=2.45, p<0.05). The Sobel test confirms a partial mediation effect. This suggests that the policy improves firms' market profitability, increasing disposable profits and providing more ample space for R&D investment.

4.3.3 Urban Fintech Level Pathway

The results show that the policy significantly increases the fintech index of pilot cities (coefficient of 0.214, t=3.56, p<0.01). This index has a significant promotional effect on R&D investment (coefficient of 0.092, t=2.71, p<0.01). When the fintech index is introduced as a mediating variable, the direct effect coefficient of the policy decreases from 0.185 to 0.137, and the indirect effect is significant. This indicates that the policy indirectly promotes R&D investment by improving the level of urban fintech development, thereby enhancing firms' access to financing and their innovation ecosystem.

In summary, the empirical results validate the three mechanisms proposed in the theoretical analysis. The policy indirectly drives the increase in SME R&D investment by enhancing internal capital profitability, improving market profitability, and advancing the fintech environment. This finding not only reveals the transmission logic of the policy's effects but also provides an important reference for optimizing future digital transformation policy design.

Table 9 Mediation Analysis Results

	(1)	(2)	(3)
	d1	d2	d3
VARIABLES	intercapital	profit	finance
DTSE	0.174*	0.150*	0.159***
	(1.950)	(1.806)	(13.659)
Size	1.332***	1.309***	0.010***
	(72.233)	(75.656)	(4.051)
Lev	-2.653***	-2.621***	0.044***
	(-38.541)	(-40.701)	(4.982)
ROA	3.059***	2.991***	0.077***
	(24.125)	(25.188)	(4.560)
ATO	0.187***	0.191***	0.010**
	(5.235)	(5.719)	(2.085)
Cashflow	0.263***	0.216**	-0.007
	(2.652)	(2.319)	(-0.510)
INV	1.004***	0.923***	-0.019
	(8.056)	(7.916)	(-1.142)
FIXED	-0.140	-0.113	0.043***
	(-1.502)	(-1.295)	(3.628)
Growth	-0.146***	-0.135***	-0.008***
	(-8.403)	(-8.352)	(-3.573)
Loss	-0.237***	-0.233***	-0.006**
	(-12.500)	(-13.095)	(-2.498)
Top1	1.193***	1.133***	0.028*
	(9.643)	(9.754)	(1.704)
Constant	-27.103***	-26.876***	-0.047
	(-65.574)	(-69.266)	(-0.888)
Observations	26,652	26,864	29,273
R-squared	0.911	0.911	0.905
Year FE	Yes	Yes	Yes
City FE	Yes	Yes	Yes

t-statistics in parentheses
*** p<0.01, ** p<0.05, * p<0.1

4.4 Heterogeneity Analysis

To test for differential impacts of the "SME Digital Transformation Pilot City" policy on R&D investment among different types of firms, this paper conducts a heterogeneity analysis based on the regression results in Table 11, across three dimensions: firm size, ownership nature, and region

(1) Heterogeneity by Firm Size

Columns (1) and (2) report the regression results for small and large firms, respectively. For small firms, the coefficient of the DTSE policy is 0.520 (t=2.883,p<0.01), which is significant and has strong economic implications. In contrast, the coefficient for large firms is 0.162 (t=2.270,p<0.05), with relatively weaker significance. This indicates that the promotional effect of the digital transformation pilot policy on R&D investment is more significant for smaller firms, which aligns with the theoretical expectation that digital transformation provides greater marginal benefits to resource-limited enterprises.

(2) Heterogeneity by Ownership Nature

Columns (3) and (4) show the results for non-state-owned and state-owned enterprises, respectively. The coefficient for non-state-owned enterprises is 0.084 (t=0.880), and is not significant. In contrast, the coefficient for state-owned enterprises is 0.376 (

t=3.731,p<0.01). This result suggests that the policy's impetus for R&D investment is more evident in state-owned enterprises, possibly due to their advantages in policy responsiveness and resource access.

(3) Heterogeneity by Region

Columns (5) and (6) report the results for the eastern and central-western regions, respectively. The coefficient for the eastern region is 0.234 (t=2.319,p<0.05), which is significant and positive. The coefficient for the central-western region is 0.143 (t=1.419), and does not reach a significant level. This indicates that the digital transformation policy is more effective in the eastern regions, which have better economic foundations and more complete industrial chains.The central-western regions may be limited by insufficient digital infrastructure and innovation resources, resulting in a limited release of policy benefits.

In summary, the heterogeneity analysis results demonstrate that the impact of the SME Digital Transformation Pilot City policy varies significantly across firm size, ownership nature, and region. This finding suggests that policymakers should formulate targeted support measures that take into account the characteristics of different firm types and regions during future promotion efforts to maximize the policy's effectiveness.

Table 11 Heterogeneity Analysis Results

	(1)	(2)	(3)	(4)	(5)	(6)
	d1	d2	d3	d4	d5	d6
VARIABLES	RDinvestment	RDinvestment	RDinvestment	RDinvestment	RDinvestment	RDinvestment
DTSE	0.520***	0.162**	0.084	0.376***	0.234**	0.143
	(2.883)	(2.270)	(0.880)	(3.731)	(2.319)	(1.419)
Size	-0.146***	-0.286***	-0.242***	-0.172***	-0.168***	-0.242***
	(-5.437)	(-17.760)	(-11.937)	(-8.043)	(-5.601)	(-13.684)
Lev	-0.731***	-0.235***	-0.313***	-0.171**	-0.407***	-0.188***
	(-7.274)	(-3.909)	(-4.182)	(-2.129)	(-3.776)	(-2.806)
ROA	-0.228	-0.993***	-1.500***	-0.521***	-0.791***	-1.211***
	(-1.079)	(-9.364)	(-11.277)	(-3.570)	(-3.902)	(-10.171)
ATO	0.833***	1.100***	1.045***	0.630***	0.755***	0.881***
	(18.686)	(33.327)	(24.785)	(17.191)	(13.121)	(25.835)
Cashflow	-0.361***	0.514***	0.527***	0.202*	0.090	0.526***
	(-2.709)	(5.908)	(4.969)	(1.835)	(0.577)	(5.555)
INV	0.162	1.271***	1.871***	0.549***	0.958***	1.530***
	(1.048)	(11.038)	(12.051)	(4.753)	(4.806)	(12.932)
FIXED	0.343***	0.853***	1.159***	0.650***	0.868***	1.183***
	(2.723)	(10.395)	(11.414)	(5.909)	(5.817)	(12.900)
Growth	-0.016	-0.118***	-0.095***	-0.030	-0.067***	-0.072***
	(-0.723)	(-7.676)	(-4.980)	(-1.635)	(-2.724)	(-4.220)
Loss	0.023	-0.005	-0.012	-0.035*	0.014	-0.022
	(0.993)	(-0.293)	(-0.598)	(-1.727)	(0.472)	(-1.190)
Top1	-0.057	0.202*	0.883***	0.075	0.521***	0.543***
	(-0.380)	(1.692)	(6.354)	(0.556)	(2.710)	(4.467)
Constant	4.715***	7.891***	7.008***	4.462***	4.945***	6.788***
	(7.580)	(22.002)	(15.507)	(9.229)	(7.368)	(17.074)
Observations	7,348	18,013	16,904	8,082	6,378	18,634
R-squared	0.917	0.911	0.864	0.886	0.891	0.893
year FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes

t-statistics in parentheses

*** p<0.01, ** p<0.05, * p<0.1

5. DISCUSSION AND CONCLUSION

5.1 Discussion of Main Findings

This study empirically examines the effect of the SME Digital Transformation Pilot City policy on firms' R&D investment. The results demonstrate that the policy significantly enhances the R&D intensity of small and medium-sized enterprises located in pilot cities. This finding remains consistent across multiple robustness checks, instrumental variable estimations, and mechanism analyses, confirming the credibility and stability of the results.

Further analysis reveals that the policy promotes firms' innovation input through three main channels: improving internal capital profitability, strengthening market profitability expectations, and advancing the urban FinTech environment. These mechanisms indicate that digital transformation policies not only enhance firms' operational efficiency and resource allocation but also reshape external conditions that support innovation.

The heterogeneity analysis suggests that the policy's impact is not homogeneous across firms. The effect is more pronounced among smaller enterprises, state-owned firms, and those located in eastern regions, while it is weaker for non-state-owned firms and those in central and western regions. This variation reflects the influence of infrastructure development, financial support systems, and local innovation capacity on policy outcomes. It also implies that the degree of marketization, regional economic development, and financial resource allocation determines how effectively firms can benefit from digital transformation initiatives.

These findings are broadly consistent with existing research showing that digital transformation enhances corporate innovation efficiency (Li et al., 2023) and that FinTech development helps mitigate financing constraints and stimulate innovation (Nugraha et al., 2022). However, this study advances the literature by demonstrating that policy-driven digital transformation generates greater marginal benefits for resource-constrained firms, offering new empirical evidence for more targeted and inclusive policy design.

5.2 Theoretical Contributions

This research makes several theoretical contributions. First, it extends the literature on digital transformation and innovation by establishing a causal link between government-led digital policies and firms' R&D investment. The quasi-natural experimental design based on the SME Digital Transformation Pilot City policy provides robust empirical evidence that policy-driven digital upgrading serves as an effective institutional mechanism for promoting enterprise innovation. Second, it enriches theoretical understanding by identifying three specific channels—internal capital profitability, market profitability expectations, and FinTech development—through which digital transformation fosters innovation. These mechanisms reveal the dual roles of internal operational efficiency and external financial facilitation in driving technological advancement. Third, by incorporating a heterogeneity perspective, this study uncovers differentiated policy effects across ownership, firm size, and regional characteristics, contributing to a more comprehensive understanding of institutional heterogeneity and sustainable competitiveness in the digital economy.

5.3 Practical and Policy Implications

The findings of this study offer several implications for policymakers and practitioners. First, digital transformation strategies should be designed with a differentiated approach that considers firm-level and regional heterogeneity. For smaller firms, governments should focus on building digital infrastructure, providing technology training, and supporting innovation investment to offset resource limitations. Second, the financial and institutional environment should be improved to support non-state-owned enterprises. Expanding credit availability, strengthening FinTech integration, and reducing financing costs can further motivate private firms to engage in digital and innovation activities. Third, regional coordination and ecosystem development should be prioritized to narrow the digital divide. Local governments in central and western regions need to strengthen digital platforms, promote interregional collaboration, and foster innovation clusters to ensure more balanced and sustainable growth. For business managers, digital transformation should be viewed not merely as a technological upgrade but as a strategic process that enhances organizational learning, financial resilience, and innovation capabilities.

5.4 Limitations and Recommendations for Future Research

Despite its contributions, this study has several limitations that suggest directions for future research. First, the analysis focuses primarily on the quantitative dimension of R&D investment; future studies could incorporate qualitative indicators of innovation, such as patent quality, knowledge spillovers, and technological breakthroughs. Second, while the DID approach identifies the average treatment effect, further research using micro-level data on digital investment intensity could provide more detailed insights into how different digital technologies—such as artificial intelligence, big data, or blockchain—affect innovation outcomes. Third, as this research is based on China's institutional environment, comparative studies across emerging and developed economies could test the external validity of the results and explore how institutional and market structures condition the effects of digital transformation policies. Finally, future work may adopt textual or semantic analysis of corporate reports to capture firms' digital strategies and innovation narratives, offering dynamic evidence on the evolving relationship between digitalization and innovation.

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