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Do Regulatory Sandboxes Promote Corporate Digital Innovation? Evidence from a Staggered Difference-in-Differences Design

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Abstract

As a novel regulatory tool designed to balance innovation incentives and risk control, the effectiveness of the regulatory sandbox is an important issue of digital economic governance. This study exploits China's regulatory sandbox pilot program as a quasi-natural experiment. Based on the data of A-share listed companies from 2011 to 2023, a staggered difference-in-differences (DID) model is used to test the impact of the regulatory sandbox on the digital innovation of enterprises. The study found that the regulatory sandbox has significantly promoted the improvement of the digital innovation capacity of enterprises, and this conclusion is still valid after a variety of robustness tests. Mechanism analysis shows that the regulatory sandbox drives enterprise digital innovation by reducing financing costs, improving risk control, increasing R&D investment and promoting digital transformation. Heterogeneity analysis shows that the policy effect is more significant in small and medium-sized enterprises, low-profitable enterprises and low-level economic development areas. This article provides empirical evidence for optimizing financial technology supervision and accurately supporting the digital transformation of enterprises.

Keywords

regulatory sandbox, digital innovation, financing costs, management efficiency, digital transformation

1. Introduction

Digital technology innovation is the first driving force for China’s digital economic development. It is not only an important path for traditional enterprises to achieve digital transformation, but also a strategic fulcrum for improving China's competitiveness[1]. Although Chinese enterprises have made remarkable progress in the field of digital patents, the penetration of digital innovation at the enterprise level is still insufficient, and some core digital technology fields are still at the end of the global value chain [2, 3]. Therefore, it is of great theoretical value and practical significance to explore how to effectively improve the digital innovation capability of enterprises.

The external regulatory environment plays an important role in shaping firms' digital innovation activities. There is a natural conflict between the high iterativeness and high risk of digital innovation and the rule lag of

the traditional regulatory system [4]. To address this challenge, the regulatory sandbox was introduced. The British Financial Conduct Authority pioneered the mechanism in 2015 to allow enterprises to test innovative products in a controlled and safe environment [5]. China took the lead in launching the pilot of financial technology innovation supervision in Beijing in December 2019, and expanded its capacity to many cities in 2020. Unlike regulatory sandbox frameworks adopted in Western economies, China's sandbox places more emphasis on the policy orientation of the real economy of financial services [6].

Existing studies mainly focus on the comparison of the normative design of the regulatory sandbox and international experience [7, 8], and quantitative testing is still insufficient. Some scholars began to discuss the effect of sandboxing to alleviate the constraints of enterprise financing [5, 9]. However, few studies have systematically examined how the regulatory sandbox affects the digital innovation capability of enterprises through multi-level transmission paths. Based on this, this paper takes China's A-share listed companies from 2011 to 2023 as the research object, regards the pilot of financial technology innovation supervision in batches as a quasi-natural experiment, and adopts a staggered difference-in-differences model to evaluate the impact of the regulatory sandbox on the digital innovation capability of enterprises.

The follow-up structure of this article is as follows: the second part is the research hypothesis; the third part is the research design; the fourth part reports the empirical results; the fifth part is the mechanism analysis and heterogeneity discussion; and the last part is the conclusions and policy suggestions.

2. Literature Review and Research Hypotheses

2.1 Corporate Digital Innovation

Regarding the economic effect of regulating the sandbox, studies have begun to discuss from both theoretical and empirical levels. In theoretical analysis, Zhang Jingzhi (2018) [8] regards it as a contingent regulatory mechanism to balance financial innovation and regulatory risks; Starting from the theory of incomplete contract, Hu Bin (2022) [7] believes that the regulatory sandbox is essentially an institutional innovation to deal with the problem of incentive distortion. Empirical evidence has also begun to emerge. Cornelli et al. (2024) [9] used British data to find that regulatory sandboxes help reduce information asymmetry and regulatory costs, thus improving the financing conditions, corporate survival and innovative output of financial technology companies. Tian Lihui and Li Yixing (2025) [5] based on the analysis of the Chinese version of the regulatory sandbox pilot shows that the policy can effectively reduce regional financial risks and promote the innovation activities of real enterprises by easing the constraints on enterprise financing. Ye Dezhu et al. (2025) [10] directly tested the impact of regulatory sandbox on enterprise digital innovation for the first time, pointing out that its mechanism mainly includes three paths: reducing uncertainty, reducing compliance costs and alleviating financing constraints.

Although the existing literature has explored enterprise digital innovation from multiple angles, there are still some shortcomings. First, regarding the transmission mechanism of digital innovation, the existing research is relatively fragmented and lacks systematic integration of multi-level and multi-path. Second, the intermediary role of digital transformation between external policies and enterprise digital innovation has not been fully identified. Third, the exploration of the heterogeneous boundary conditions of the regulatory sandbox effect is not comprehensive enough, especially among enterprises with different property rights and industry technical characteristics, the differences in policy effects still lack in-depth analysis. In response to the above shortcomings, this article tries to build a complete effect path from macro policies to micro enterprises, and deeply explore its intrinsic mechanism, in order to provide a stronger empirical basis for the design of adaptive governance policies.

2.2 Institutional Background and Research Hypotheses

2.2.1 Regulatory Sandbox Policy

The People's Bank of China officially launched the pilot of financial technology innovation supervision in December 2019, which marked the beginning of the Chinese version of the regulatory sandbox. In January 2020, the first batch of pilots landed in Beijing, and then expanded to Shanghai, Shenzhen, Chongqing, Hangzhou, Suzhou, Chengdu, Guangzhou, Xiong'an New District, Hebei Province and other nine regions. In

2021, the pilot scope was further expanded to Shandong, Hubei, Guizhou, Guangxi, Shanxi, Anhui, Henan, Gansu and other provinces, gradually forming a regulatory innovation pattern covering many provinces and cities across the country. The Financial Technology Development Plan (2022-2025) issued in January 2022 takes the acceleration of the digital transformation of financial institutions as the main line, and emphasizes the need to make full use of financial technology innovation supervision tools to ensure that financial innovation is carried out under the framework of prudential supervision. The Central Financial Work Conference held in October 2023 further emphasized the comprehensive strengthening of financial supervision and the prevention and resolution of risks. At the same time, it affirmed the mechanical value of the regulatory sandbox to promote innovation under the premise of risk control.

However, digital innovation itself has the characteristics of high investment, long cycle and strong uncertainty, and is more sensitive to changes in the external policy environment. Even with the promotion of policies, the actual innovation behavior of enterprises will still be affected by many factors.

2.2.2 Regulatory Sandbox Pilots and Corporate Digital Innovation

By establishing a continuous communication mechanism between regulators and enterprises, the regulatory sandbox transforms vague policy expectations into clear regulatory guidelines, effectively reducing the uncertainty faced by enterprises. At the same time, the sandbox provides an institutional guarantee for enterprises to obtain external financing and alleviates the financial constraints of R&D investment[9]. Ye Dezhu et al. (2025)[10] empirically found that sandbox drives enterprise digital innovation by reducing uncertainty, reducing compliance costs and alleviating financing constraints. Based on this, this article proposes:

H1: Participation in regulatory sandbox programs positively affects firms' digital innovation capability.

2.2.3 Mechanism Analysis Hypotheses

(1) Regulatory Sandboxes and Financing Costs

Innovative activities face financing constraints due to information asymmetry (Hall, 2002) [11]. The sandbox sends a positive signal of “regulatory recognition” to the market, reducing information asymmetry, thus reducing financing costs [5]. Accordingly, it is proposed that:

H2: Regulatory sandbox policies can significantly reduce the financing cost of enterprises, thereby promoting digital innovation of enterprises.

(2) Regulatory Sandboxes and Management Efficiency

The sandbox has built an information interaction platform to reduce decision-making bias and force enterprises to improve internal governance[12, 13]. Governance indicators such as the size of the board of directors are directly related to enterprise performance [14]. Accordingly, it is proposed that:

H3: The regulatory sandbox policy can significantly improve the management efficiency of enterprises, and the improvement of management efficiency will promote the improvement of the digital innovation capability of enterprises.

(3) Regulatory Sandboxes and R&D Expenditure

Research and development activities have positive externalities and require policy intervention [15]. The reduction of financing costs and institutional costs directly release the financial resources used by enterprises for research and development [10]. Accordingly, it is proposed that:

H4: The regulatory sandbox policy can significantly increase firms' R&D investment, thereby promoting the improvement of the digital innovation capability of enterprises.

(4) Regulatory Sandboxes and Digital Transformation

Sandbox provides a “safe space” for enterprises to test digital technology, reducing the risk of trial and error [9]. Digital transformation indirectly promotes innovation by improving information transparency and absorption capacity [17, 16]. Accordingly, it is proposed that:

H5: Regulatory sandbox policies enhance firms' digital innovation capability through digital transformation.

3. Research Design

3.1 Data Selection

This article selects Chinese A-share listed companies from 2011 to 2023 as research samples. Refine the provincial pilot areas to the prefecture-level city level. The digital innovation data of enterprises comes from the digital economy database of China Economic Network, and the financial data comes from the CSMAR database. The sample of the financial industry, ST or *ST, and missing key variables was eliminated, and finally 28,759 observations were obtained. All continuous variables were winsorized at the 5% level in both tails.

3.2 Definition of Key Variables

3.2.1 Dependent Variable: Corporate digital innovation capability

Corporate Digital Innovation Capability. Using the method of Wu Fei (2021) [18], the word frequency of 76 related keywords in the annual report is counted from the two levels of "low-level technology application" and "technology practice application", which is obtained by weighted calculation.

3.2.2 Independent Variable: Regulatory Sandbox Pilot Program

This article takes the pilot policy of financial technology supervision as a quasi-natural experiment. The sample of the enterprise registered in the pilot city is set as the treatment group, Treat is recorded as 1, the sample of the enterprise registered in the non-pilot city is set as the control group, and Treat is set as 0. Set the time dummy variable post before and after the implementation of the pilot policy to 0 and 1 respectively.

3.2.3 Control Variables

This article refers to the practices of Yang Qing et al. (2025) [19] and Tian Lihui et al. (2025) [5] to control the following variables: (1) Enterprise level: cash flow ratio (Cf), shareholding ratio of the largest shareholder (Top), corporate leverage ratio (Lev), property rights nature (Soe), duality, operating income growth rate (Growth).At the urban level: regional gross domestic product is taken from the logarithm (GDP), population density (PD), industrial structure (IS), see Table 1 below for details:

Table 1: Variable Definitions

Variable	Definition
DIC	Digital innovation capability, measured as the natural logarithm of one plus the weighted frequency of digital technology-related terms.
DID	Policy dummy variable, constructed as the interaction term Post × Treat.
Cf	Cash flow ratio, measured as the net cash flow generated from operating activities divided by total assets at year-end.
Top	Shareholding ratio of the largest shareholder, calculated as the number of shares held by the largest shareholder divided by the total number of shares outstanding.
Lev	Leverage ratio, measured as total liabilities at year-end divided by total assets at year-end.
Soe	Dummy variable for ownership type. State-owned enterprises are assigned a value of 1, and non-state-owned enterprises are assigned a value of 0.
Duality	Dummy variable for corporate governance structure. It equals 1 if the positions of chairman of the board and chief executive officer (CEO) are held by the same individual, and 0 otherwise.
Growth	Revenue growth rate, calculated as (increase in operating revenue ÷ operating revenue in the previous year) × 100%.
GDP	Natural logarithm of regional GDP.
PD	Population density, measured as the total regional population divided by the administrative area of the region.
IS	Industrial structure, measured as the ratio of the value added of the secondary industry to that of the tertiary industry.

3.2.4 Model Specification

This paper constructs the following staggered difference-in-differences (DID) model to identify the causal effect of regulatory sandbox pilots on the digital innovation capabilities of enterprises. The econometric model is specified as follows:

$$DICit = \alpha + \beta DIDit + \delta Xit + \mu i + \lambda t + \varepsilon it \quad (1)$$

Here, the subscripts i and t denote the firm and the year, respectively. The dependent variable, DIC_{it}, represents the digital innovation-driven capability of firm i in year t. The key explanatory variable, Did_{it}, is the dummy variable representing the regulatory sandbox pilot policy—the focus of this study—μ_i and λ_t denote firm fixed effects and year fixed effects, respectively. ε_{it} represents the random error term. In the empirical analysis, standard errors are clustered at the city level.

4. Empirical Results and Analysis

4.1 Descriptive Statistics

The descriptive statistics of the main variables are shown in the descriptive statistics in Table 2 below. The mean value of the core explained variable enterprise innovation driving force DIC is 3.53, the standard deviation is 0.31, and the difference between the maximum value and the minimum value is small, indicating that the variable exhibits relatively stable variation. The average value of the core variable regulatory sandbox policy Did is 29%, indicating that 29% of sample urban enterprises are located in the pilot area of the regulatory sandbox, which is consistent with the policy characteristics of China's batch promotion of the pilot. On the control variable, the standard deviation of each variable is about 1, indicating a relatively balanced distribution of the variables.

Table 2: Descriptive Statistics

Variable	Mean	Standard Deviation	Minimum	Maximum	Observations
DIC	3.53	0.31	3.28	4.62	28759
Did	0.29	0.46	0	1	28759
Cf	0.03	0.99	-2.90	3.12	28759
Top	0.04	0.97	-2.12	3.72	28759
Lev	0.02	0.97	-1.85	2.31	28759
Soe	0.06	0.99	0	1	28759
Duality	0.02	1.01	-0.60	1.67	28759
Growth	-0.02	1.00	-1.31	3.56	28759
GDP	0.03	1.15	-10.23	0.96	28759
PD	0.03	1.01	-7.50	1.79	28759
IS	0.14	0.93	-2.30	2.01	28759

4.2 Baseline Regression Results

Table 3 reports the baseline regression results. Column (1) includes only the core explanatory variable, and the DID coefficient is significantly positive at the 1% level. In Column (2), after including all control variables and controlling for individual and year fixed effects, the DID coefficient is 0.0150, significant at the 5% level. This indicates that, compared to non-pilot regions, enterprises in pilot regions experienced a significant enhancement in digital innovation capabilities following policy implementation; thus, Hypothesis H1 is supported.

4.3 Parallel Trend Test

In order to ensure the validity of double differential estimation, this paper first first conducts a descriptive trend analysis to calculate the average value of the treatment group, that is, the first batch of regulatory sandbox pilot enterprises and the control group in 2019-2020 on the core dependent variables by year, and intuitively judge whether the change trends of the first two groups of policy implementation are roughly parallel. As shown in Figure 1 on the left, then, a more rigorous event research method is used to generate dummy variables of the relative time of policy implementation (based on the previous period of the policy), and incorporate the two-way fixed effect model for regression, while controlling the individual and time fixed effect and related covariables. As shown in Figure 2 on the right, whether the parallel trend hypothesis is valid by observing whether the coefficients of the dummy variables in each period before the policy and their confidence intervals are significantly different from zero; if the coefficients in each period before are not significant, it indicates that there is no systematic difference between the treatment group and the control group before the policy, which satisfies the parallel trend assumption.

The estimated coefficients of each period before the implementation of the policy are relatively small and the confidence interval contains 0. There is no significant difference between the two groups of trends, which satisfies the parallel trend hypothesis. The coefficient for the policy implementation period is positive but not significant, and the post-policy period 1-3 coefficient is significantly positive, indicating that the policy effect is about one year behind.

Table 3: Baseline Regression Results

Variables	Corporate Digital Innovation Capability (DIC)	
	(1)	(2)
Did	0.1863***	0.015**
	(0.0069)	(0.0066)
Cf		-0.0029**
		(0.0014)
Top		-0.0144***
		(0.0049)
Lev		0.0080
		(0.0051)
Soe		-0.0129*
		(0.0070)
Duality		0.0029
		(0.0029)
Growth		-0.0037
		(0.0040)
GDP		0.0028**
		(0.0013)
PD		0.0442**
		(0.0189)
IS		-0.0062
		(0.0108)
Constant	3.5300**	3.5311**
	(0.0018)	(0.0017)
Observations	28328	28328
Year Fixed Effects	Yes	Yes
Firm Fixed Effects	Yes	Yes
Adjusted R^2	0.6636	0.6647

Figure 1: Innovation Trends in the Treatment and Control Groups

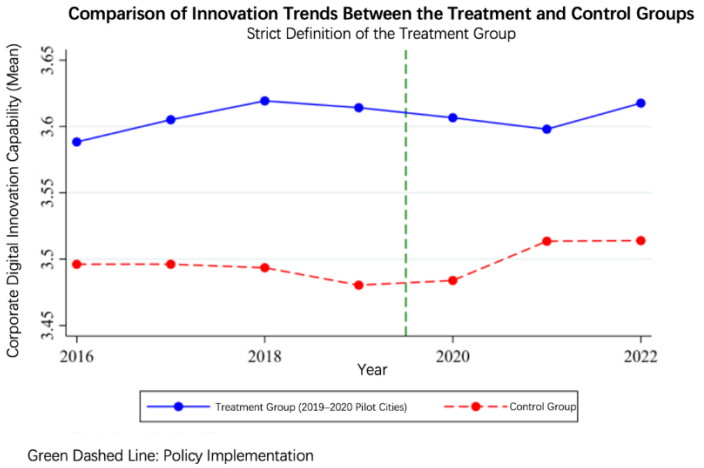
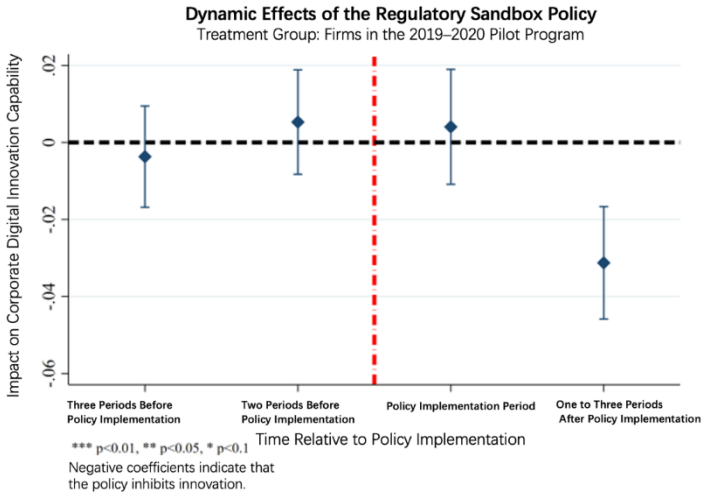


Figure 2: Parallel Trend Test Based on the Event Study Approach



4.4 Robustness Tests

4.4.1 Alternative Measure of the Dependent Variable

In order to verify the robustness of the conclusion of this article, this paper replaces the measurement method of the core explained variables for empirical testing. Column (2) of Table 4 replaces the dependent variable with the amount of enterprise digital patent grants. Compared with the benchmark regression result in the first column, the regression coefficient of the regulatory sandbox is 0.0013, which is significantly positive at the 5% level. The result is consistent with the symbol of the benchmark regression coefficient, proving the robustness of the research conclusion. This shows that even after adopting different measurement methods, the regulatory sandbox pilot still promotes the driving force of enterprise digital innovation.

4.4.2 Alternative Clustering Level

Since the control variables of this study involve the enterprise and urban levels, the error items may increase with the expansion of the cluster scope. This paper adopts the method of replacing cluster hierarchy to verify the stability of the regression coefficient. The results show that columns (1) to (3) supervise the impact of sandboxes on the corporate digital innovation capability of enterprises at the enterprise, city and provincial levels respectively. All three results are significantly positive at the level of 5%, which further proves that regulatory sandbox policies have the ability to significantly improve the corporate digital innovation capability of enterprises at different cluster levels.

4.4.3 Double Machine Learning

This paper applies three DML models: average treatment effect model, partial linear model, and interactive effect model to study the effect of financial regulatory sandbox policies on digital innovation of regional enterprises. The estimated coefficients of these three models are 0.0146, 0.0133 and 0.0214 respectively, all of which are significantly positive at the 1% level. Among them, the coefficient of the interaction effect is higher than the coefficient of the benchmark regression result, indicating that under the interaction between the policy effect and the characteristics of the enterprise, the financial regulatory sandbox policy has a potential role in promoting the driving force of enterprise innovation. The partially linear model relaxes the linearity assumption, and the results have the same symbol as the benchmark regression, indicating that the research conclusion is not affected by the function form, which reduces the risk of model bias. The ATE model flexibly captures nonlinear relationships and complex interactions. From the direct impact of policies, the results further support the conclusion of this article, that is, the regulatory sandbox promotes the driving force of digital innovation of enterprises.

Table 4: Robustness Test: Alternative Dependent Variable

Variables	Baseline Regression (1)	Alternative Dependent Variable (Digital Patent Grants) (2)
Did	0.015** (0.0066)	0.0013** (0.0003)
Cf	0.015** (0.0066)	0.0028** (0.0014)
Top	-0.0029** (0.0014)	-0.0141*** (0.0051)
Lev	-0.0144*** (0.0049)	0.0083 (0.0051)
Soe	0.0080 (0.0051)	-0.0113 (0.0074)
Duality	-0.0129* (0.0070)	0.0030 (0.0028)
Growth	0.0029 (0.0029)	-0.0034 (0.0040)
GDP	-0.0037 (0.0040)	0.0027** (0.0013)
PD	0.0028** (0.0013)	0.045** (0.012)
IS	0.0442** (0.0189)	-0.0059 (0.0109)
Control Variables	Yes	Yes
Firm/Year Fixed Effects	Yes	Yes
Observations	28328	28328
Constant	3.5311** (0.0017)	3.5285*** (0.0019)
Adjusted R^2	0.6647	0.6658

Table 5: Robustness Test: Alternative Clustering Levels

Variables	Corporate Digital Innovation Capability (DIC)		
	(1)	(2)	(3)
Did	0.0149** (0.0068)	0.015** (0.0066)	0.015** (0.0061)
Cf	-0.0029* (0.0016)	-0.0029** (0.0014)	-0.039** (0.0018)
Top	-0.0144*** (0.0050)	-0.0144*** (0.0049)	-0.001** (0.000)
Lev	0.0080** (0.0038)	0.0080 (0.0051)	0.039 (0.0025)
Soe	-0.01286** (0.0062)	-0.0129* (0.0070)	-0.026* (0.0015)
Duality	0.0029 (0.0026)	0.0029 (0.0029)	0.007 (0.006)
Growth	-0.0037 (0.0031)	-0.0037 (0.0040)	-0.011 (0.0012)
GDP	0.0028** (0.0013)	0.0028** (0.0013)	0.002*** (0.000)
PD	0.0443*** (0.0149)	0.0442** (0.0189)	0.054** (0.021)
IS	-0.0062 (0.0092)	-0.0062 (0.0108)	-0.046 (0.0073)
Constant	3.5312*** (0.0018)	3.5311** (0.0017)	3.209*** (0.0017)
Observations	28328	28328	28328
Firm/Year Fixed Effects	Yes	Yes	Yes
Firm-level Clustering	Yes	No	No
City-level Clustering	No	Yes	No
Province-level Clustering	No	No	Yes
Adjusted R^2	0.6648	0.6647	0.6648

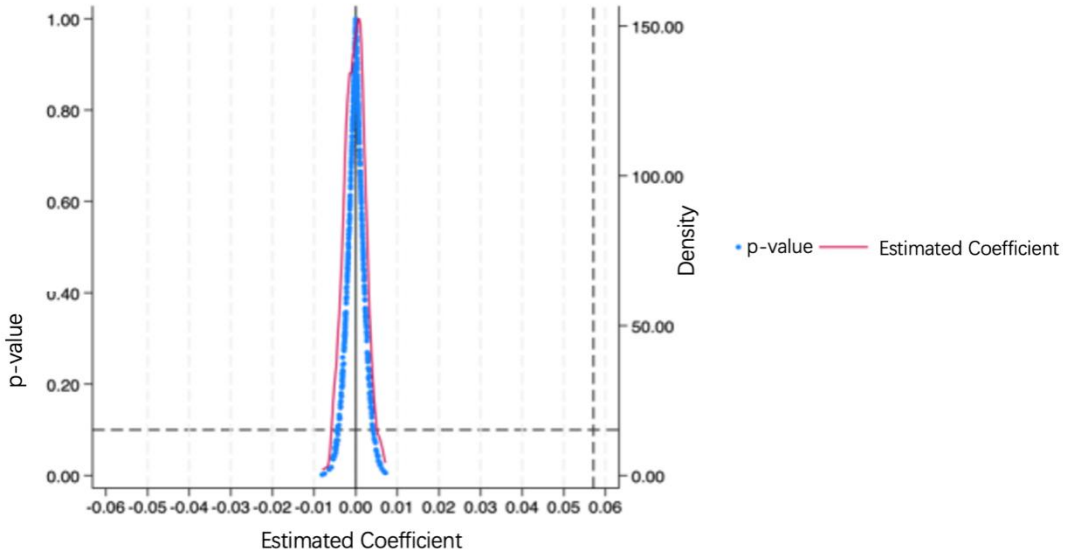
Table 6: Robustness Test: Double Machine Learning (DML)

Variables	Corporate Innovation (IC)		
	Average Treatment Effect	Partially Linear Model	Interactive Regression Model
Did	0.0146*** (0.1668)	0.0133*** (0.0048)	0.0214*** (0.0025)
Constant	-0.0126*** (0.0015)		
Observations	28759	28759	28759

4.4.4 Placebo Test

In order to exclude the influence of unobservable factors, this paper adopts a placebo test. This paper randomly generates 500 false policy shocks, and substitutes these false shocks into the original difference-in-differences model for estimation. As shown in Figure 3, the mean value of the estimated coefficient of false shock is close to zero and shows a normal distribution. This result is consistent with theoretical expectations, indicating that false policy shocks should not have a systemic impact in the absence of real policy intervention. The P value of most false shocks exceeds 0.10, which means that these randomly generated "policy" effects are not statistically significant. This shows that the policy effect is not caused by random factors or model missetting.

Figure 3: Placebo Test



5. Further Analysis

5.1 Mechanism Analysis

Regarding the mechanism effects, this paper considers four influencing pathways:

$$\mathrm{Mit} = \alpha + \beta \mathrm{Mdidit} + \gamma \mathrm{Xit} + \mu i + \lambda t + \varepsilon it \quad (2)$$

Among them, "Mit" represents four mechanisms: financing cost, management efficiency, R&D expenditure, and digital transformation.

5.1.1 Reducing Financing Costs

Regulatory sandboxes provide enterprises with diverse financing channels, reduce information asymmetry, and alleviate financing constraints encountered during digital innovation. Drawing on the approach of Wei Zhihua and Zeng Aimin (2013) [20], this paper measures financing costs as the ratio of corporate financial expenses to total assets and assesses the financing impact of the regulatory sandbox policy by examining changes before and after its implementation. An analysis of the results in Table 7, Column (1), reveals that the

regression coefficient for financing cost is -0.0039 and is significantly negative at the 5% level, indicating that the regulatory sandbox policy can significantly reduce corporate financing costs. Further enhance digital innovation capabilities in two respects: first, reduce borrowing costs and optimize debt structures to increase the share of long-term debt, thereby facilitating corporate investment in long-term, high-risk projects such as R&D. Second, the broadening of financing channels and the improvement of the financing environment have provided a long-term, stable financial foundation for corporate digital innovation. Regulatory policies improve the financing environment for enterprises, provide policy support for the sustainable development of digital innovation, and enhance the driving force behind such innovation; this is consistent with the findings of Ye Dezhu (2025) [10], thereby confirming Hypothesis H2.

5.1.2 Improving Management Efficiency

Financial regulatory sandboxes significantly reduce the institutional costs of innovation for enterprises by granting them exemptions, while also allowing for the testing of innovative products and mitigating regulatory uncertainty. Drawing on the approach of Xie Jun (2007) [14], this paper uses the ratio of board size to total corporate assets as a measure of corporate management efficiency. Qi Yudong and Liu Huanhuan (2022) [12] point out that regulatory sandboxes boost the number of corporate innovation patents by reducing technological uncertainty through real-world experimental results, mitigating information asymmetry through effective information exchange, enhancing internal regulatory efficiency, and lowering the costs of business operations. As shown in Column (2) of Table 7, the management efficiency coefficient is 42.1629 and is significantly positive at the 1% level; this result indicates that the regulatory sandbox policy has significantly enhanced corporate management efficiency. Wang Tao and Liu Dongwang (2025) [13] have proven that when companies improve information transparency and internal governance levels by participating in regulatory sandboxes, external investors' trust in the company increases, and the difficulty and cost of companies obtaining external financing are significantly reduced, thus providing more abundant financial guarantees for digital innovation activities. The regulatory pilot establishes a platform for information exchange among enterprises, enhances management efficiency, mitigates potential contractual risks, and facilitates resource flow to boost innovation efficiency, thereby further substantiating H3.

5.1.3 Increasing R&D Investment

By reducing financing costs, regulatory sandboxes directly improve the external financing environment for enterprises, creating the financial feasibility for them to allocate more resources to research and development activities. This study uses the amount of expensed R&D investment from the CSMAR database as the measure of corporate R&D expenditure. Based on the results in Column (3) of Table 7, the coefficient for R&D expenses is 3,845.51 and is significantly positive at the 10% level; this indicates that under the pilot policy, enterprises gained greater room for trial and error within a relatively relaxed innovation environment, and this institutional advantage significantly boosted their R&D investment intensity. Sandbox pilot policies incentivize digital technology innovation among manufacturing enterprises by enhancing channels for R&D funding. When enterprises shift more resources from short-term operational activities to long-term R&D, it indicates that they are proactively adapting to policy directives and market demands, placing greater emphasis on cultivating core competitiveness and sustainable development capabilities. This strategic adjustment helps the enterprise maintain sustained innovation momentum in the digital economy and establish a long-term competitive advantage in the market; therefore, Hypothesis H4 is supported.

5.1.4 Promoting Corporate Digital Transformation

Financial regulatory sandboxes provide enterprises with room for innovation, alleviate financing constraints, enhance regulatory efficiency, and boost R&D investment, thereby further fostering corporate digital transformation. This paper adopts the approach of Wu Fei (2021) [18], measuring the level of corporate digital transformation based on word frequency statistics from the texts of listed companies' annual reports. The regression results in Column (4) of Table 7 show that the coefficient for the level of corporate digital transformation is 7.2528, which is significant at the 1% level. The results demonstrate that regulatory sandboxes can significantly foster the development of digital technologies within enterprises. The advancement of digital transformation further enhances corporate digital innovation capabilities—a transmission mechanism supported by an extensive body of literature. First, digital transformation fosters innovation by enhancing information transparency [16]; Second, digital transformation indirectly enhances

innovation performance by strengthening corporate absorptive capacity [17]; Third, digital transformation drives innovation output by optimizing internal controls and the quality of information disclosure. The institutional advantages fostered by sandbox policies create conditions for enterprises to adopt advanced digital technologies, enabling them to achieve intelligent, platform-based, and interconnected operations while establishing a long-term, stable driver for innovation[5]. In summary, regulatory sandboxes drive corporate digital transformation—and thereby significantly enhance digital innovation capabilities—through mechanisms such as reducing institutional costs, increasing information transparency, and strengthening absorptive capacity; this further confirms the validity of Hypothesis H5.

Table 7: Mechanism Analysis Results

Variables	Financing Costs (cost) (1)	Management Efficiency (regulatory) (2)	R&D Expenditure (rd) (3)	Digital Transformation (dt) (4)
Did	-0.0039**	142.1629***	33845.51*	7.2528***
	(0.0017)	(36.3034)	(20429.29)	(2.4319)
Cf	-0.0006*	4.5147	2056.352	-0.2971**
	(0.0003)	(10.7963)	(1704.632)	(0.1427)
Top	-0.0031***	410.3953***	-1327.69*	-0.8234*
	(0.0007)	(22.5440)	(7567.845)	(0.4981)
Lev	0.0181***	-68.3965***	-3478.335	0.8077**
	(0.0014)	(17.7917)	(5906.493)	(0.3465)
Soe	-0.0015	0.3796	-1575.776	1.2350**
	(0.0010)	(29.2263)	(1525.049)	(0.5083)
Duality	0.0007	-4.0288	581.1823	0.0759
	(0.0004)	(13.6567)	(1525.049)	(0.2160)
Growth	0.0023***	43.5697***	331.5452	-0.4368*
	(0.0009)	(15.5938)	(1183.55)	(0.2248)
GDP	0.0005**	1.9455	-228.0193	-0.3496
	(0.0003)	(12.6431)	(550.87)	(0.3595)
PD	0.0064*	321.9115***	-97.36	9.0555***
	(0.0037)	(60.6434)	(17386.98)	(3.3204)
IS	-0.0077***	29.4968	-2016.39	-4.8005*
	(0.0018)	(40.2521)	(18118.84)	(2.5884)
Constant	0.0039***	2409.281***	35091.79***	258.822***
	(0.0004)	(12.4577)	(3578.971)	(0.6272)
Observations	27641	28328	21178	28305
Adjusted R^2	0.4002	0.7955	0.6926	0.9721
Firm/Year Fixed Effects	Yes	Yes	Yes	Yes

5.2 Heterogeneity Analysis

5.2.1 Firm Size Heterogeneity

This study is grouped from the perspective of enterprise scale. It is divided into large-scale enterprises and small-scale enterprises based on the median firm size. From the regression results, it can be seen that there is a significant difference in the impact of financial regulatory sandbox on the corporate digital innovation capability of enterprises, and the characteristics of enterprise scale are an important influencing factor for policy response. Table 8 (1) (2) below shows that the policy has a significant effect on small-scale enterprises. The policy effect is insignificant among large firms. And there is also a negative impact coefficient. The reason for this result may be: on the one hand, small enterprises are usually flexible and can adapt to policy changes faster and adjust innovation strategies in the face of external shocks. On the other hand, Ye Dezhu (2025) [10] pointed out that financing constraints will inhibit enterprise innovation activities, which is a key factor restricting the improvement of enterprise innovation capacity. Due to the weak capital and financial communication capacity of small enterprises, their dependence on external financing is much higher than that of large enterprises. Innovation activities have the characteristics of high uncertainty, long cycle and high risk of failure. Therefore, small enterprises will reduce R&D investment, while large enterprises have sufficient capital financing capacity, and the impact of sandbox supervision pilot is relatively small. Small enterprises

respond more strongly to regulatory sandbox policies, which proves their important role in market innovation. At the same time, it also reflects their high sensitivity to policy support.

5.2.2 Profitability Heterogeneity

In terms of profitability, this study uses the total return on assets (roa) to distinguish the profitability of enterprises. It can be concluded from Tables 8 (3) and (4) that enterprises with low profitability are significantly affected by regulatory pilot policies, and enterprises with high profitability are also positively affected by policies, but they do not reach the significant level of statistics. This difference may be due to the fact that enterprises with low profitability may face resource constraints and technological disadvantages, and innovative activities are more easily inhibited by financing constraints[9]. The space provided by the regulatory sandbox for enterprises to freely research and develop has eased financing constraints to a certain extent. For high-profitable enterprises, they may possess advanced technology or resources in the market and have sufficient information, so the impact is relatively small.

5.2.3 Heterogeneity in Economic Development Levels

This article is divided into high and low economic development zones based on the macroeconomic purchasing power parity index and the median. According to Table 8 (5) (6), in areas with low economic development level, the promotion of regulated pilot policies is relatively significant, while the policy effect is insignificant in economically developed regions and have not reached a significant level. It may be because the regional financing environment is underdeveloped at the low level of economic development, and the information asymmetry of external investors is more serious. Enterprises are supported by policies in the pilot, which has a stronger positive impact on enterprise financing. Cornelli (2024)[9] once used one of the variables of information asymmetry to explore the mechanism, and came to the conclusion that the sandbox policy reduces the information asymmetry between investors and enterprises, as well as the costs caused by regulatory uncertainty, further demonstrating that the regulatory sandbox has significantly promoted the digital innovation capability of enterprises.

Table 8: Heterogeneity Analysis Results

Variables	Firm Size		Profitability		Economic Development Level	
	(1) Small	(2) Large	(3) Low	(4) High	(5) Low	(6) High
Did	0.0314***	-0.0035	0.0222**	0.0080	0.0262**	-0.0037
	(0.0095)	(0.0089)	(0.0093)	(0.0113)	(0.0107)	(0.0102)
Cf	-0.014	-0.0050	0.0010	-0.0058	-0.0021	-0.0038**
	(0.0018)	(0.0018)	(0.0023)	(0.0025)	(0.0019)	(0.0018)
Top	-0.0238***	-0.0061	-0.0117	-0.01814**	-0.0102*	-0.0144
	(0.0071)	(0.0057)	(0.0086)	(0.0086)	(0.0056)	(0.0138)
Lev	0.0048	0.0003	0.0037	0.0168**	0.0013	0.0112
	(0.0051)	(0.0065)	(0.0053)	(0.0065)	(0.0047)	(0.0102)
Soe	-0.0220**	-0.0102	-0.0073	-0.0094	-0.0098	-0.0151
	(0.010)	(0.0079)	(0.0072)	(0.0107)	(0.0078)	(0.0142)
Duality	0.0048	0.0039	0.0035	0.0055	0.0070**	0.0006
	(0.0045)	(0.0040)	(0.0035)	(0.0044)	(0.0032)	(0.0048)
Growth	0.0008	0.0042	-0.0059	-0.0018	-0.0007	-0.0073
	(0.0545)	(0.0067)	(0.0059)	(0.0044)	(0.0038)	(0.0076)
GDP	0.0032*	0.0019	0.0029*	0.0027	0.0029**	0.0023
	(0.0017)	(0.0020)	(0.0015)	(0.0018)	(0.0014)	(0.0030)
PD	0.0562***	0.0184	0.0227	0.0566**	0.0129	0.0242*
	(0.0166)	(0.0245)	(0.0219)	(0.0186)	(0.0163)	(0.0123)
IS	-0.0161	-0.0042	0.0089	-0.0207	0.0136	-0.0094
	(0.0150)	(0.02453)	(0.0148)	(0.0159)	(0.0100)	(0.0153)
Constant	3.5247***	3.5350***	3.5223***	3.5444***	3.501***	3.5865***
	(0.0064)	(0.000)	(0.000)	(0.000)	(0.0077)	(0.0128)
Observations	13889	14152	13973	13595	16126	12008
Adjusted R^2	0.7056	0.6881	0.6923	0.6820	0.6297	0.722
Firm/Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes

6. Conclusions

This paper employs a staggered DID model to systematically evaluate the impact of China's regulatory sandbox pilot on the digital innovation capability of enterprises. The study found that the regulatory sandbox has significantly improved the digital innovation capability of enterprises. The mechanism analysis reveals that the regulatory sandbox has jointly driven the digital innovation of enterprises by reducing the financing cost of enterprises, improving internal management efficiency, stimulating R&D investment and promoting digital transformation. Heterogeneity analysis shows that this policy effect is more obvious in resource-constrained firms, that is, small and medium-sized enterprises, low-profitable enterprises and enterprises in areas with low economic development level benefit more. This study reveals the transmission path of the regulatory sandbox from institutional empowerment to enterprise innovation, which provides empirical evidence for optimizing financial technology supervision and accurately supporting the digital transformation of enterprises.

There are certain shortcomings in this research. First of all, the measurement of digital innovation capability is based on the annual report text, and there may be measurement bias. Secondly, despite the DID method, it is still difficult to completely eliminate the problem of self-selection. Future research can try to use more detailed text analysis or case studies to deeply explore the micro-decision-making process of enterprises in the sandbox. In addition, the long-term effects of regulatory sandboxes, such as the impact on market structure and consumer welfare, are also worth further tracking.

Based on this, this article puts forward the following suggestions:

First, expand the coverage of sandboxes and implement differentiated access. The access threshold should be further lowered, special channels should be set up for small and medium-sized enterprises and underdeveloped areas, and technical guidance and risk compensation should be provided, so that policy dividends can benefit vulnerable subjects in innovation more fairly.

Second, deepen the financing and credit enhancement function of sandbox. Pilot banks are encouraged to develop exclusive financial products such as “sandbox loans”, and guide long-term capital such as venture capital and private equity to dock with projects in the sandbox, forming a positive cycle of “sandbox authentication - credit enhancement - financing available”.

Third, improve the mechanism of sandbox withdrawal and achievement transformation. Standardized sandbox exit guidelines should be introduced to clarify the conversion conditions and follow-up supervision arrangements for successful projects. At the same time, establish a platform for displaying achievements and docking to accelerate the innovation plan from “inside the sandbox” to “in the market”.

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