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Xia Liu

liuxia@mail.usts.edu.cn

Suzhou University of Science and Technology

Jing Xu

Suzhou University of Science and Technology

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Abstract: Green credit subsidy policy (GCSP) is a policy enacted by government and bank to reduce financial costs and stimulate green innovation (GI) in heavily polluting firms. This study employs a difference-in-differences model to investigate the impact of GCSP on green innovation levels among these firms. Based on the data of heavily polluting enterprises listed on the A-share market from 2012 to 2023, the results show that the GCSP effectively promotes the overall green innovation, including substantive and strategic green innovation in heavily polluting enterprises. We further validate the causal relationship through parallel tests, placebo test, propensity score matching and other robustness checks. The impact of GCSP is more pronounced in state-owned enterprises, large-scale enterprises, firms located in regions with low level of environmental regulation, regions with higher level of government support, and firms operating in industries with lower market concentration. Our research reveals three financial mechanisms: GCSP promotes green innovation and transformation by enhancing external supervision, improving firm reputation, and reducing environmental compliance costs. This study broadens the research perspective on how green credit subsidies influence corporate green innovation and emphasize the importance of government in encouraging corporate green innovation and directing social investment to alleviate financial constraints.

Keywords Green finance • Environmental innovation • External supervision • Firm reputation • Environmental compliance cost

Introduction

Intensifying climate change increasingly threatens economic sustainability. In 2015, the Paris Agreement is put forward to forge a global commitment, which can channel financial flows toward low emission and climate resilient pathways. To implement this accord, governments and financial institutions have jointly adopted a range of green financial policies that redirect capital from polluting sectors to clean energy and green industries, accelerating low-carbon transition (Gao et al., 2026). Green financial policies now constitute an essential pillar of global institutional frameworks for mitigating climate risk.

As a major economy in the world, China plays a crucial role in promoting the sustainable development of the world economy. However, rapid economic growth has caused enormous environmental problems, such as urbanization and desertification. China urgently needs to promote the green transformation of energy-intensive and highly polluting firms to achieve sustainable economic development. In 2020, China put forward the "dual-carbon" goals of reaching peak carbon dioxide emissions before 2030 and achieving carbon neutrality before

2060 at the seventy-fifth session of the General Assembly, which demonstrates its firm commitment to advancing the strategies of ecological priority, conservation and intensive use, as well as green and low-carbon development. The report of the 20th National Congress of the Communist Party of China further emphasizes the importance of promoting the green and low-carbon transmission of economic and social development.

In response to the sustainable development goals, China actively promotes green finance. Specifically, China integrates environmental externalities into financial decision-making and reallocate social capital towards green and low-carbon activities. As defined by the 2016 Guidelines for establishing a green financial system, it refers to financial services that support economic activities for environmental protection, climate action, and resource efficiency. At present, the green financial system in China comprises three core components: financial instruments, incentive mechanisms, and standard-setting infrastructure.

As a pillar financial policy, green credit subsidy policy refers to a policy under which local governments provide partial or full loan interest subsidies to green enterprises that meet specific criteria. It combines fiscal subsidies and credit support to effectively reduce the financing costs of firm green innovation and provide strong policy support for promoting the green transformation of firms. Accordingly, exploring the effectiveness of green credit subsidy policy on green innovation is of great significance for the realization of the "dual-carbon" goals.

Green credit subsidy policy aims to alleviate the financing pressure of heavily polluting firms and encourage them to engage in pollution prevention, cleaner production, and the implementation of green projects (Hong et al., 2023). Since 2017, green credit subsidy policies have emerged on a large scale across various regions. By the end of 2023, more than 50 cities had issued relevant documents to promote green credit interest subsidy policies, such as Xiamen, Ningbo, Shanghai and Huzhou. However, there is limited research on the policy effects and mediating mechanisms of green credit subsidy policies. This paper argues that, compared with single green fiscal or financial policies, green credit subsidy policies involve bank screening, which can effectively identify and curb corporate "greenwashing" behaviors. Additionally, these policies can reduce loan interest rates through fiscal subsidies, thus stimulating financial institutions to provide loans to enterprises (Liu et al.,2025).

1 Literature review

The existing scholars mainly focus their research on how single economic policy affects firm green innovation, yet there is a lack of further investigation into the impact of combined green credit and fiscal subsidy policies on firm innovation, specifically interest-subsidized green credit policies. Most researchers support the view that green financial policies promote corporate green innovation by optimizing resource allocation and reducing information asymmetry (Zhou et al., 2025), and they agree that fiscal policies positively influence green corporate governance by internalizing the negative externalities of pollution emissions and the positive externalities of green production. However, some scholars have raised doubts, arguing that single green financial policies have certain limitations and even negative effects. For instance, Ma et al. (2023) analyzed green credit policies lead to the compliance cost effect and credit constraint effect, which will finally inhibit the technological innovation of high-polluting enterprises. They

found that green credit policy may have potential adverse impacts on certain firms. Ding et al. (2022) further deepened the understanding of these negative effects from the perspectives of credit constraints and information transmission.

A small number of scholars have conducted research on green credit interest subsidy policies. Existing literature primarily focuses on how such policies promote corporate green behaviors, such as green innovation, green transformation, and carbon emission reduction. He et al. (2024) examines how green credit interest subsidy policies improve firm green transition by expanding the scale of green credit and fostering green technological innovation. Zhang et al. (2024) further evaluate the effectiveness of corporate green transformation from three dimensions—environmental performance, operational development performance, and innovation performance. Through empirical analysis, they prove that green credit interest subsidies improve environmental and operational performance, but the impact on innovation is minimal. Other researchers focus on corporate greenwashing behavior. Hong et al. (2023) study the policy effectiveness from the perspective of coordination between fiscal and financial policies and claim that green credit interest subsidy policy encourages banks to identify greenwashing risks and help firms better fulfill their environmental social responsibilities. Wu & Zeng (2026) introduce a new mechanism perspective, emphasizing that green credit interest subsidies can suppress greenwashing by reducing supply chain concentration.

The academic research on corporate green innovation from the perspective of coordination between fiscal and financial policies remains insufficient. This study takes heavily polluting listed companies in the A-share market as the sample and employs a difference-in-differences approach to examine the impact of green credit interest subsidy policies on green innovation in heavily polluting enterprises. This study extends previous research by exploring the underlying mechanisms and offering policy recommendations. Compared with previous studies, this paper makes two potential marginal contributions. First, by identifying the relationship between green credit interest subsidy policies and corporate green innovation, it opens up a new research perspective for exploring the synergistic effects of green finance and fiscal policies. Second, it comprehensively and thoroughly investigates the transmission channels through which green credit interest subsidies influence corporate green innovation, providing fresh insights for optimizing green socioeconomic development and accelerating the green transformation of growth models.

2 Theoretical background and research hypothesis

2.1 Green credit subsidy policy and green innovation of heavily polluting firms

According to Porter hypothesis, appropriate environmental regulations can incentivize firms to innovate technologically, offsetting part or even all of the compliance costs. Green credit policies initially implemented in 2012 and is different from traditional mandatory environmental regulations that rely on administrative penalties. Green credit policies guide market resource allocation and encourage firms toward greener operations, motivating heavily polluting enterprises to adopt green technological innovations and gradually achieve green transformation (Wang et al., 2026). Specifically, green credit policies achieve a transition from end-of-pipe governance to source prevention through measures such as raising environmental

entry thresholds, implementing differentiated lending practices, and strengthening information disclosure. Based on externality theory, green credit policies transform the negative externalities of heavily polluting enterprises into financial costs and encourage firms to invest in emission reduction and green process innovation. As an upgraded version of green credit policies, green credit interest subsidy policies fully leverage their "inducement" and "pressure" effects to drive green innovation among heavily polluting enterprises (Song et al., 2025). First, enterprises receiving green credit subsidies benefit from government endorsement, which can help attract attention from institutional investors and increase their willingness to invest in green projects. As main targets of green credit subsidy policies, heavily polluting enterprises that launch green innovation initiatives can achieve substantive green transformation. Green loans and government subsidies can greatly alleviate financing constraints. Moreover, by the upfront-payment-subsidy approach, this policy encourages these enterprises to pursue green innovation to qualify for subsidies. Second, green credit subsidies impose higher environmental compliance costs on heavily polluting enterprises, pressuring them to meet environmental standards and transition toward greener operations (Ma et al., 2023). Meanwhile, aiming to avoid credit and compliance risks, financial institutions reduce loan amounts to heavily polluting enterprises and narrow their access to financing and forcing them to engage in green innovation and industrial upgrading. Ongoing supervision by financial institutions and the government further pressures these enterprises to implement green innovations. Enterprises must submit environmental and social risk reports prior to obtaining green loans, and relevant authorities will monitor their environmental performance to prevent greenwashing and ensure genuine green technological advancement after receiving funding. The theoretical foundation of Porter Hypothesis and Externality Theory explains how green credit subsidy policies influence green innovation and the first hypothesis is proposed:

Hypothesis 1. (H1): Green credit interest subsidy policies promote green innovation among heavily polluting firms.

2.2 The mediating role of external supervision

When heavily polluting enterprises successfully apply for green loans and receive fiscal interest subsidies, it helps attract investors and promotes corporate green innovation through external oversight. The act of obtaining subsidized financing sends a positive signal to the market and draws green investor attention, encouraging green investors to invest in and participate in corporate decision-making. The green investors tend to support green projects and innovations. Furthermore, individual or institutional investors interested in green initiatives can directly invest in subsidized firms, reducing costs associated with information search and risk assessment. Once green investors enter a company, through professional investment, information discovery, and activist engagement they influence corporate decisions (Fan et al., 2025). Additionally, green investors supervise improvements in production technologies and green innovation. Therefore, we propose the following hypothesis:

Hypothesis 2. (H2): The green loan subsidy policy promotes green innovation among heavily polluting enterprises by strengthening external supervision.

2.3 The mediating role of firm reputation

Obtaining green loan interest subsidies helps improve a firm's media attention and reputation (Lin & Hong, 2025). According to Signaling Theory, firms need to strengthen internal management, adjust strategic decisions, and uphold corporate culture to enhance their image and social reputation. First, green loan subsidy policies provide government endorsement and official recognition of a firm's environmentally friendly practices, which significantly boosts corporate reputation (Luo & Wang, 2025). Heavy-polluting firms with strong reputations and policy support are more likely to gain investors' confidence, attract potential stakeholders, and alleviate their financing constraints. Second, applying for green loans and subsidies requires firms to disclose more comprehensive and transparent environmental information. Enterprises actively pursuing green transformation can improve their reputation through such disclosures (Fatima et al., 2025), whereas firms engaging in greenwashing will suffer reputational damage and receive less credit support. In this paper, we propose the following hypothesis:

Hypothesis 3. (H3): Green loan interest subsidy policies promote green innovation among heavy-polluting enterprises by enhancing their reputation.

2.4 The mediating role of environmental compliance costs

By guiding and regulating firms' actions, environmental regulations can amplify the positive effect of green credit subsidy policies on corporate green innovation. Under a single green finance policy, firms may disguise environmental information to achieve "greenwashing." However, environmental regulations penalize high-pollution behaviors, forcing firms to reduce emissions and transform production methods, which will stimulate substantive green innovation (Zhang et al., 2025). As an environmental regulation tool, environmental compliance costs exert pressure on high-pollution firms to actively pursue green innovation (Tian et al., 2023). Thus, environmental compliance cost act as a critical mediator between green credit subsidy policy and green innovation.

Hypothesis 4. (H4): Green credit interest subsidy policies promote green innovation among heavily polluting enterprises by reducing environmental compliance costs.

3 Models, variables and data

3.1 Sample selection and data sources

This study selects listed companies in China's heavily polluting firms and spans from 2012 to 2023. To ensure research accuracy, we apply several screening criteria: (1) excluding financial sector listed companies; (2) excluding firms marked as ST or *ST; (3) removing firms with financial abnormalities or consecutive three-year operating losses. The final sample comprises 4,985 observations.

The green credit subsidy policy data are sourced from information documents disclosed on provincial and municipal government websites regarding substantive green finance incentive policies. This dataset covers green credit interest subsidy policies in nine national-level green finance innovation reform pilot zones across six provinces, including Zhejiang and Guangdong, as well as 13 provincial-level green finance innovation reform pilot zones established independently by regions such as Sichuan and Guangxi. Financial data for this study come

from the CSMAR database, city data from annual urban statistical yearbooks, and patent data from the China Research Data Service Platform (CNRDS) and the State Intellectual Property Office (SIPO). We merge the above data accordingly. To mitigate the impact of extreme values, we winsorize all the continuous variables at 1% level.

3.2 Definition of variables

Table 1 provides a comprehensive overview of the variables employed in our empirical analysis. We systematically categorize the variables into three groups: dependent variables, independent variables and control variables.

Dependent variables

This study measures corporate green innovation from two aspects: the number of green patent applications and the efficiency of green innovation. Following the method of Chen and Wang (2022), the total number of green patent applications filed by a firm is used to measure its green innovation. The volume of green patent applications is positively correlated with a company's willingness and output level in green technological innovation, accurately reflecting its green technological innovation activities. Since granted green patents involve a certain time lag, the total number of green patent applications provides a timely reflection of a firm’s green innovation condition in a given year. Following the approach of Hu et al. (2023), green patent applications are categorized into substantive innovation and strategic innovation based on different innovation motivations. Substantive innovation drives fundamental technological transformation and represents high-level innovation. Therefore, the number of green invention patent applications is used as the measurement indicator. Strategic innovation merely aligns with corporate strategy and typically requires only low-level technological improvements. Therefore, the number of green utility patent applications serves as the corresponding indicator. Research by Liu and Tang (2025), the efficiency of corporate green innovation is measured by the ratio of total green patent applications to R&D investment, reflecting the process through which firms achieve greater innovation output with relatively lower innovation input. Green management efficiency reflects how effectively management activities indirectly promote green innovation; higher values indicate stronger support for green initiatives through managerial practices.

Independent variables

This study employs a difference-in-differences model to examine the impact of green credit interest subsidy policies on green innovation among heavily polluting enterprises. The sample period is from 2012 to 2023. Following Pan et al. (2019), we identify heavily polluting industries based on the "Notice on issuing the list of industry classification for environmental protection inspection of listed companies" released by the ministry of ecology and environment. If a listed company belongs to an industry subject to environmental protection inspection, it is classified as a heavily polluting enterprise and included in our research sample. We focus exclusively on these heavily polluting firms. For firms located in regions where the green credit interest subsidy policy has been implemented, the policy dummy variable (treat) is assigned a value of 1, placing

them in the treatment group. Otherwise, treat equals 0 and they belong to the control group. We define post as a time dummy variable, with the implementation date of the green credit interest subsidy policy serving as the cutoff point. Before the policy was introduced, the post value for cities where firms were registered is set to 0, while after the policy implementation, this value becomes 1.

Control variables

Following the methods of Hong et al. (2023) and Liu et al. (2023). Firm-level control variables include firm size, leverage, return on assets, firm age, equity turnover, cash flow ratio, revenue growth, cost-to-expense profit rate, natural logarithm of net intangible assets and net fixed assets. City-level control variables include economic development level, industrial structure and credit supply.

Table 1：Definition of main variables

Type	Variable name	Variable measures
Dependent variables	Overall green innovation (Innovation)	Total green patent applications
	Substantive green innovation (Innovation 1)	Green invention patent applications
	Strategic green innovation (Innovation 2)	Green utility patent applications
	Granted green innovation (Innovation_Ac)	Green granted patent applications
	Green innovation efficiency (Efficiency 1)	Total green patent applications/ R&D investment
	Green management efficiency (Efficiency 2)	Total green patent applications/administrative expenses
Independent variables	Policy dummy (Treat)	Dummy equals 1 if the city where the firm is registered implements a green credit subsidy policy, and 0 otherwise
	Time dummy (Time)	Dummy equals 1 after the policy is enacted in the firm's city, and 0 otherwise
	Difference-in-differences (DID)	Interaction term between Treat and Post
Control variables	Firm size (Size)	Natural logarithm of total assets at year-end
	Leverage (Lev)	Total liabilities/ total assets
	Return on assets (ROA)	Net profit / average total assets
	Firm age (Age)	Years since establishment
	Equity turnover (EQT)	Sales revenue / average shareholders'

		equity
	Cash flow ratio (Cashflow)	Operating cash flow / total assets
	Revenue growth (Growth)	Revenue increase / previous year's total revenue
	Cost-to-expense profit rate (CPR)	Total profit / (operating costs + selling expenses + administrative expenses + financial expenses)
	Net intangible assets (Inasset)	Natural logarithm of net intangible assets plus one
	Net fixed assets (Fixasset)	Natural logarithm of net fixed assets
	CEO-chairman duality (Dual)	Dummy equals 1 if the CEO and chairman are the same person, and 0 otherwise
	Economic development level (pGDP)	Natural logarithm of per capita GDP at city level
	Industrial structure (Secondary)	Added value of secondary industry / GDP
	Credit supply (TC)	Year-end total loans of financial institutions / regional GDP

Source: own

3.3 Model setting

To examine the impact of green credit subsidy policies on corporate green innovation, this study establishes the following model (1):

$$\mathrm{Innovation}_{it} = \beta_0 + \beta_1 \mathrm{Post}_{it} * \mathrm{Treat}_{it} + \beta_2 X_{it} + \gamma_i + \mu_i + \varepsilon_{it} \quad (1)$$

In the above model, subscripts i and t denote firms and years, respectively. $\mathrm{Innovation}_{it}$ represents the natural logarithm of the total number of green patent applications filed by firm i in year t, reflecting the level of green innovation for that firm in the given year. In the regression results, this study focuses primarily on the coefficient β_1 of the two interaction terms; a positive and statistically significant β_1 suggests that the green credit interest subsidy policy promotes green innovation among heavily polluting enterprises. X_{it} represents control variables, while r_i and μ_i respectively reflect firm fixed effects and year fixed effects.

4 Empirical results

4.1 Descriptive statistics

Table 2 presents the descriptive statistics of the variables. Specifically, the mean number of green patent applications per firm is 4.818, indicating a low level of innovation and considerable variation across firms（SD = 11.23）. The number of green invention patent applications exceeds that of green utility model patent applications, meanwhile the number of granted green patents is significantly lower than the total number of applications. The mean value of the time dummy variable Post is 0.170, meaning that 17.0% of the sample falls in the period after policy implementation between 2012 and 2023. The mean of the treatment group dummy variable

Treat is 0.271, indicating that only 27.1% of heavily polluting enterprises are located in regions where green credit interest subsidy policies were implemented, reflecting a relatively low overall proportion. The remaining control variables also exhibit varying degrees of differences.

Table 2: Descriptive statistics

VARIABLES	N	Mean	p50	SD	Min	Max
Innovation	4985	4.818	1	11.23	0	73
Innovation1	4985	2.381	0	6.715	0	48
Innovation2	4985	2.397	0	5.443	0	33
Innovation_Ac	4985	3.367	1	7.571	0	48
Efficiency1	4985	6.858	0.360	22.99	0	178.6
Efficiency2	4985	1.525	0.183	3.044	0	18.48
Treat	4985	0.271	0	0.444	0	1
Post	4985	0.170	0	0.376	0	1
DID	4985	0.166	0	0.372	0	1
Size	4985	22.58	22.31	1.411	20.23	26.55
Lev	4985	0.414	0.413	0.192	0.0590	0.839
ROA	4985	0.0470	0.0400	0.0460	-0.0800	0.198
CPR	4985	0.129	0.0840	0.169	-0.182	1.037
Cashflow	4985	0.133	0.101	0.105	0.0100	0.513
Growth	4985	0.137	0.0750	0.331	-0.417	1.875
Intasset	4985	19.32	19.14	1.668	15.93	24.20
Fixasset	4985	21.26	20.99	1.709	18.02	26.12
ATO	4985	1.369	1.040	1.121	0.213	6.842
Dual	4985	0.237	0	0.425	0	1
Age	4985	10.54	9	7.857	0	27
Secondary	4985	0.426	0.436	0.110	0	73
pGDP	4985	96836	89112	46238	0	48
TC	4985	3.627	3.150	1.704	0	33

Source: own

4.2 Parallel trend test

This paper employs an event study approach to analyze the dynamic economic effects of green credit interest subsidy policies. Figure 1-4 presents the parallel trend test results for the impact of green credit interest subsidy policies on corporate green innovation between 2012 and 2023. The results show that the regression coefficients were not significant before policy implementation, but became significantly positive afterward. This indicates that the green credit subsidy policy has a significant positive effect on corporate green patent applications, and the parallel trend assumption is satisfied.

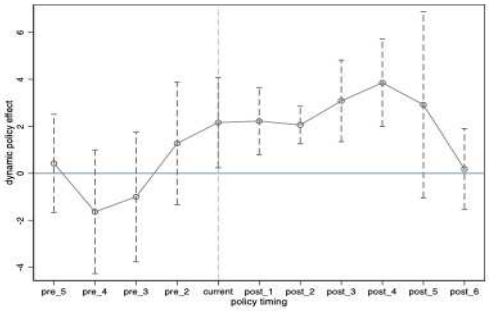

Figure 1: Total green patent applications

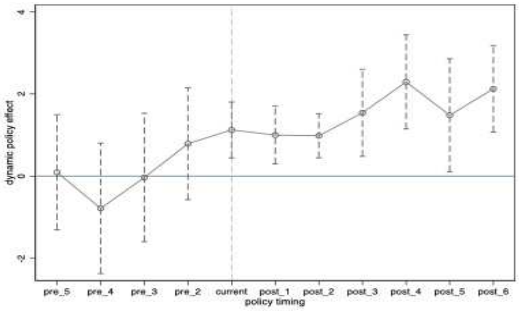

Figure 2: Green invention innovation patent applications

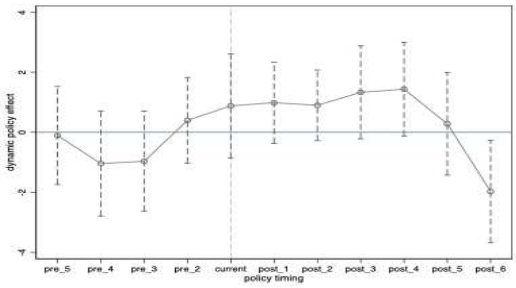

Figure 3: Green utility patent applications

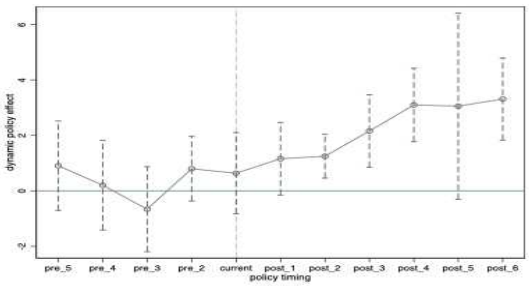

Figure 4: Green granted patent applications

Source: own

4.3 Baseline regression

Table 3 reports the regression results of the model. In columns (1), (2), (3), and (4), the estimated coefficients of the core explanatory variable DID are significantly positive after controlling for other influencing factors, indicating that the green credit interest subsidy policy promotes green innovation among heavily polluting firms, thus supporting Hypothesis 1. However, the estimated coefficients in columns (5) and (6) are not significant, suggesting that the green credit interest subsidy policy has not significantly improved firms' green innovation efficiency or management efficiency.

Table 3: Baseline regression

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	Innovation	Innovation 1	Innovation 2	Innovation_Ac	Efficiency 1	Efficiency 2
DID	2.622***	1.235**	1.269***	1.326*	0.200	0.127
	(0.648)	(0.422)	(0.235)	(0.669)	(1.886)	(0.131)
Size	2.370***	1.238***	1.240***	1.340***	-0.624	0.256
	(0.451)	(0.328)	(0.280)	(0.312)	(2.116)	(0.162)
Lev	-6.892***	-3.874***	-2.726**	-5.035***	6.153*	-1.083
	(1.762)	(0.846)	(1.099)	(0.917)	(2.976)	(0.685)
ROA	12.41*	3.958	8.777**	10.82**	-16.40	-0.836

	(6.191)	(3.625)	(3.208)	(3.967)	(17.70)	(2.191)
Age	0.179	0.0888*	0.0921	0.218**	-0.347*	0.0464
	(0.109)	(0.0419)	(0.0776)	(0.0898)	(0.189)	(0.0299)
ATO	0.402	0.341**	0.0205	0.461***	-0.372	-0.0453
	(0.265)	(0.127)	(0.142)	(0.0999)	(0.657)	(0.0977)
Cashflow	2.270	1.931**	0.0814	2.087**	5.236**	-0.0205
	(1.503)	(0.824)	(0.737)	(0.699)	(2.112)	(0.684)
Growth	0.654	0.293	0.335	-0.0551	1.724	0.353
	(0.479)	(0.220)	(0.310)	(0.200)	(1.207)	(0.245)
CPR	-3.466**	-1.465	-2.089***	-3.557**	0.408	0.322
	(1.506)	(1.077)	(0.592)	(1.253)	(6.140)	(0.606)
Fixasset	-0.199	-0.431	0.189	0.277	0.622	-0.115
	(0.616)	(0.370)	(0.262)	(0.321)	(1.083)	(0.211)
Intasset	0.536	0.552*	-0.0204	0.530**	-1.701*	-0.144**
	(0.390)	(0.272)	(0.150)	(0.236)	(0.832)	(0.0575)
Dual	-0.293	-0.0730	-0.309*	-0.218	-0.896	-0.105
	(0.271)	(0.157)	(0.143)	(0.285)	(1.197)	(0.124)
Secondary	-8.255	-1.731	-6.660*	-4.466	-0.824	-2.874
	(4.661)	(1.689)	(3.419)	(3.394)	(8.305)	(1.850)
pGDP	-0.585	-0.00529	-0.709***	0.175	-2.918	-0.449
	(0.533)	(0.435)	(0.226)	(0.396)	(1.754)	(0.349)
TC	-0.548	-0.366**	-0.192	-0.232	1.237	-0.0667
	(0.438)	(0.162)	(0.333)	(0.249)	(0.975)	(0.172)
Firm FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Constant	-43.12**	-25.21***	-17.83*	-43.58***	71.21***	7.519
	(15.14)	(6.874)	(9.555)	(7.857)	(21.39)	(5.908)
Observations	4,926	4,926	4,926	4,926	4,926	4,926
R-squared	0.709	0.686	0.650	0.688	0.492	0.526

Note: t-statistics in parentheses; *p<0.1, **p<0.05, ***p<0.01.

Source: own

4.4 Robustness check

To ensure the robustness of the baseline regression results, a series of tests will be conducted below.

Placebo test

To further verify whether the results are driven by other unobservable factors, a placebo test was conducted following the method of Chen et al. (2025). A new treatment group was created by randomly selecting some firms from 737 heavily polluting enterprises as a "placebo test group", and a uniform "placebo test time" was randomly assigned. The difference-in-differences

(DID) estimation was then repeated 500 times to obtain a distribution of estimated coefficients for the interaction terms, as shown in Figure 5. Figure 5 displays the kernel density and histogram of the placebo test results. The estimated coefficient for the interaction term is 2.622, and it can be observed that the estimated treatment effect lies on the right side of the placebo effect distribution. Moreover, the two-sided p-value is 0.046, leading to a strong rejection of the null hypothesis at the 5% significance level. This indicates that the green credit interest subsidy policy's impact on corporate green innovation has not been influenced by other policies or random factors, confirming the robustness of the results.

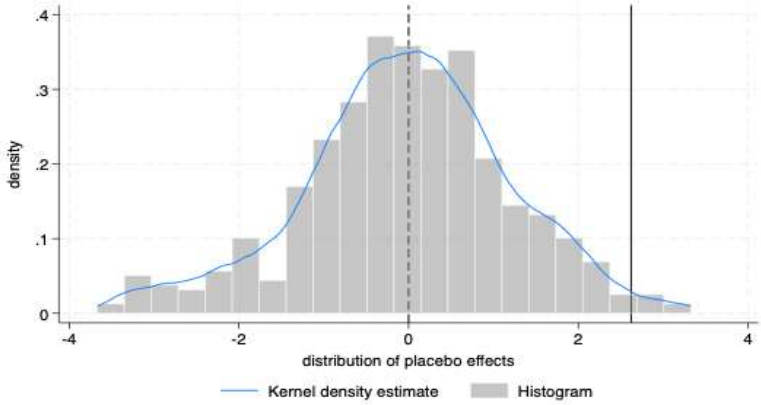

Figure 5: Placebo test

Source: own

PSM-DID (Propensity score matching combined with Difference-in-differences)

This study employs propensity score matching (PSM) to address endogeneity arising from sample differences between the treatment and control groups. Given the substantial difference in number of observations between the treatment and control groups, kernel matching is adopted to identify companies with characteristics similar to those of the treated firms based on features of heavily polluting firms. After PSM matching, a balance test of propensity score matching is conducted, and the results are reported in Figure 6. The regression results after matching remain consistent with the baseline regression, indicating that the findings pass the robustness check and it is shown in Table 4.

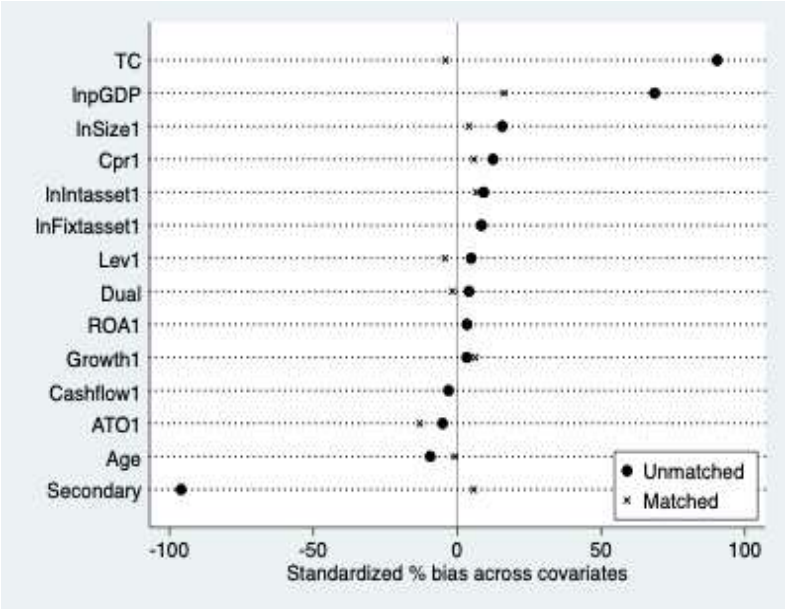

Figure 6: Covariate balance test of propensity score matching

Source: own

Table 4: PSM-DID regression results

VARIABLES	(1)	(2)	(3)
	Innovation	Innovation1	Innovation2
DID	1.222**	0.704**	0.503*
	(0.516)	(0.318)	(0.273)
Control variable	YES	YES	YES
Firm FE	YES	YES	YES
Year FE	YES	YES	YES
Constant	-37.66***	-15.42*	-23.12***
	(12.96)	(7.985)	(6.850)
Observations	4,723	4,723	4,723
R-squared	0.682	0.671	0.629

Source: own

Lag the main independent variables

The main independent variable is lagged by one period. To address endogeneity concerns arising from reverse causality, lagging the key independent variable by one period helps isolate unidirectional causal effects. Therefore, this study uses the one-year-ahead total number of green patent applications to measure corporate green innovation for further analysis, with results reported in Table 5. The results show that the regression coefficient for the one-year-lagged main independent variable is positive and statistically significant, consistent with the baseline regression results. This robustness check strengthens the credibility of the policy's positive effect in improving corporate innovation.

Table 5: Lagged main independent variables

VARIABLES	(1)	(2)	(3)	(4)
	Innovation	Innovation1	Innovation2	Innovation_Ac
L.DID	2.368***	1.174**	1.002***	1.287**
	(0.567)	(0.400)	(0.224)	(0.539)
Control variable	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Constant	-42.81*	-24.99*	-17.98	-46.02***
	(22.11)	(11.23)	(12.39)	(9.666)
Observations	3,591	3,591	3,591	3,591
R-squared	0.737	0.711	0.680	0.717

Source: own

Tobit regression to address truncated data issues

The data of dependent variables in this study, especially green innovation patent applications, contains a high proportion of zero values, primarily due to the relatively small number of firms applying for green patents. Since our independent variable is left-censored at zero, this paper thus further employs a tobit regression model to address the problem of many firms not applying for green patents in the main regression model. Accordingly, this study focuses only on heavily polluting enterprises that have applied for green patents and examines the impact of green credit interest subsidy policies on their level of green innovation. Table 6 reports the regression results. The regression coefficients of the main explanatory variables are all significantly positive, indicating that the conclusions of this study are robust.

Table 6: Tobit regression

VARIABLES	(1)	(2)	(3)	(4)
	Innovation	Innovation1	Innovation2	Innovation_Ac
DID	2.262***	1.330**	1.046***	1.507***
	(0.670)	(0.550)	(0.399)	(0.477)
Control variable	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Constant	-145.3***	-113.3***	-82.93***	-119.5***
	(9.581)	(8.007)	(5.486)	(6.809)
Observations	4,985	4,985	4,985	4,985
Number of firms	796	796	796	796

Source: own

Eliminating the influence of other environmental policies

During the implementation period of the green credit interest subsidy policy, some regions also introduced and implemented related environmental policies. As a result, sample firms might have been influenced by other policies in adjacent periods, potentially affecting the conclusions of this study. In 2017, the overall plan for establishing pilot zones for green finance reform and innovations was issued, introducing incentive measures such as interest subsidies, relending, and fiscal and tax benefits for green credit in pilot areas. This study introduces a dummy variable (GFReform) indicating whether each city established a green financial innovation and reform pilot zone in the current year or later. The policy regression coefficient in Table 7 remains positive and significant, indicating that even after excluding the influence of other concurrent green finance policies, the conclusions of this study remain robust.

Table 7: Eliminating the influence of other environmental policies

VARIABLES	(1)	(2)	(3)	(4)
	Innovation	Innovation1	Innovation2	Innovation_Ac
DID	2.655***	1.160**	1.379***	1.412**
	(0.648)	(0.395)	(0.241)	(0.641)
Control variable	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Constant	-42.94**	-25.61***	-17.25*	-43.12***
	(14.38)	(6.551)	(9.165)	(7.616)
Observations	4,926	4,926	4,926	4,926
R-squared	0.709	0.686	0.651	0.688

Source: own

4.5 Heterogeneous analysis

Based on the above research, we can conclude that the green credit interest subsidy policy promotes green innovation. However, the effectiveness of this policy may vary under different external conditions. Therefore, we explore heterogeneity at the firm and regional levels， including firm ownership, firm size, environmental regulations, government support for green development and market concentration.

Heterogeneity analysis based on firm ownership

State-owned and non-state-owned listed companies in China exhibit significant differences in green transformation and corporate governance. State-owned enterprises (SOEs) enjoy advantages in accessing green credit support from banks. Moreover, SOEs generally invest more in innovation and achieve higher innovation performance than private enterprises. Therefore, we argue that green credit subsidy policies are likely to favor state-owned enterprises during implementation, leading to a greater improvement in the quality of green innovation among SOEs compared to non-SOEs. To examine these effects, we conduct group

regressions based on ownership type and use interaction terms to test for heterogeneous policy impacts.

Table 8 presents the regression results. The coefficient of the policy interaction term for state-owned enterprises is 6.298, significantly positive at the 1% level, whereas the corresponding coefficient for non-state-owned enterprises is -1.357, significantly negative at the 1% level. This indicates that the green credit subsidy policy promotes green innovation among state-owned listed companies but suppresses green innovation in non-state-owned listed firms. One potential explanation is that financing constraints and institutional barriers hinder the green transformation of non-state-owned enterprises, thereby limiting their capacity for green innovation.

Table 8: Firm ownership

VARIABLES	State-owned			non-state-owned		
	(1)	(2)	(3)	(4)	(5)	(6)
	Innovation	Innovation 1	Innovation 2	Innovation	Innovation 1	Innovation 2
DID	6.298***	3.550***	2.252***	-1.357***	-0.832***	-0.473*
	(0.959)	(0.604)	(0.519)	(0.509)	(0.317)	(0.258)
Control variable	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Constant	-2.314	14.69	-17.31	-71.70***	-40.16***	-33.12***
	(26.99)	(17.01)	(14.61)	(14.16)	(8.823)	(7.168)
Observations	1,964	1,964	1,964	2,951	2,951	2,951
R-squared	0.743	0.705	0.690	0.623	0.648	0.531

Source: own

Heterogeneity analysis based on firm size

Differences in firm size can affect the effectiveness of green credit interest subsidy policies. This study groups firms based on their year-end total assets, with those in the upper quartile classified as large-scale firms and those in the lower quartile classified as small-scale firms. To examine the impact of firm size heterogeneity, we conduct separate regression analyses for large-scale and small-scale firms.

Table 9 presents the results of the grouped regressions. The interaction term coefficient for large-scale listed companies is 6.457, significantly positive at the 1% statistical level, whereas the interaction term coefficient for small-scale firms is -0.168, which is not statistically significant. This demonstrates that the green credit interest subsidy policy has a significant positive effect on green innovation among large-scale heavily polluting firms. This may due to the fact that large firms enjoy clear advantages in creditworthiness, making them more likely to obtain green

credit support. Additionally, large-market-capitalization firms are typically subject to greater government oversight and policy guidance, encouraging increased investment in green innovation projects and accelerating their green transformation.

Table 9: Firm size

VARIABLES	Small-scale firms			Big-scale firms		
	(1)	(2)	(3)	(4)	(5)	(6)
	Innovation	Innovation 1	Innovation 2	Innovation	Innovation 1	Innovation 2
DID	-0.168	-0.0623	-0.106	6.457***	3.013***	2.648***
	(0.412)	(0.343)	(0.184)	(1.592)	(0.982)	(0.867)
Control variable	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Constant	-24.46	-13.98	-10.48	-97.13*	-27.12	-68.47**
	(15.81)	(13.16)	(7.047)	(50.85)	(31.38)	(27.68)
Observations	1,137	1,137	1,137	1,210	1,210	1,210
R-squared	0.608	0.533	0.645	0.747	0.728	0.687

Source: own

Heterogeneity analysis based on environmental regulation

The impact of green innovation on enterprises may vary across regions due to differences in the intensity of environmental regulations (ER). This study measures the strength of environmental regulation as the ratio of investment in industrial pollution control to industrial value added. Then we divide regions into two groups based on the median value: high and low environmental regulation groups.

The results of the grouped regression are shown in Table 10. In low-regulation regions, the interaction term coefficient is significantly positive, whereas in high-regulation regions, although the coefficient is negative, it is not statistically significant. This may be because firms in low-regulation regions face less pressure to comply with environmental standards, resulting in lower opportunity costs for green innovation. The green credit interest subsidy policy provides targeted financial support, alleviating financing constraints and further promoting green innovation among these firms.

Table 10: Environmental regulations

VARIABLES	Low-regulation regions			High-regulation regions		
	(1)	(2)	(3)	(4)	(5)	(6)
	Innovation	Innovation 1	Innovation 2	Innovation	Innovation 1	Innovation 2

DID	3.834***	2.041***	1.545***	1.232	0.501	0.442
	(0.747)	(0.485)	(0.386)	(1.033)	(0.610)	(0.583)
Control variable	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Constant	-14.37	4.543	-19.12*	-44.24**	-23.20*	-27.22**
	(21.37)	(13.88)	(11.05)	(22.16)	(13.07)	(12.49)
Observations	2,211	2,211	2,211	2,087	2,087	2,087
R-squared	0.787	0.754	0.735	0.701	0.696	0.645

Source: own

Heterogeneity analysis based on government support for green development

Government support for green development operates through fiscal subsidies, technological assistance, and market regulation. In conjunction with green credit policies, such support redirects corporate innovation resources toward green sectors. In regions with high level of government green support, policies can significantly stimulate corporate green innovation by leveraging sound institutional environments, efficient financial resource allocation, and a diversified set of policy tools. In contrast, in areas with low level of green support, policies are often constrained by the absence of standards, information asymmetry, and financial repression, making it difficult to achieve intended outcomes. Following the approach of Zhu et al. (2024), this study measures government environmental support (ES) using the proportion of fiscal expenditure on environmental protection. The group regression results are shown in Table 11. The interaction term coefficient for regions with high government green support is 3.089, significantly higher than the baseline regression coefficient, indicating that fiscal green support enhances the effectiveness of green credit interest subsidy policies in promoting corporate green innovation.

Table 11: Government support for green development

VARIABLES	**Low level of support**			**High level of support**		
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
	Innovation	**Innovation 1**	**Innovation 2**	**Innovation**	**Innovation 1**	**Innovation 2**
DID	1.319	0.854*	0.487	3.089***	1.663***	1.186***
	(0.842)	(0.499)	(0.468)	(0.738)	(0.464)	(0.375)
Control variable	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES

Constant	-7.131	19.30	-31.71**	-25.76	-18.47	-8.471
	(23.33)	(13.84)	(12.97)	(21.77)	(13.69)	(11.08)
Observations	2,308	2,308	2,308	2,350	2,350	2,350
R-squared	0.703	0.709	0.635	0.765	0.739	0.723

Source: own

Heterogeneity analysis based on market concentration

Firms in low-market-concentration regions face relatively limited external competitive pressures, leading them to adopt business strategies that emphasize long-term stable development and compliant operations, thereby enhancing competitiveness and promoting sustainable growth. This study uses the Herfindahl-Hirschman Index (HHI) to measure industry concentration intensity; a lower HHI indicates smaller differences in firms' revenues within the industry and higher market competition. Firms with HHI values below the first quartile are classified as high-concentration firms, while those above the third quartile are categorized as low-concentration firms. As shown in column (4) of Table 12, the green credit interest subsidy policy promotes green innovation among firms in less concentrated industries.

Table 12: Market concentration

VARIABLES	**High market concentration**			**Low market concentration**		
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
	Innovation	**Innovation1**	**Innovation2**	**Innovation**	**Innovation1**	**Innovation2**
DID	0.995	0.715	0.312	2.363***	1.215***	0.819**
	(0.751)	(0.489)	(0.375)	(0.717)	(0.425)	(0.397)
Control variable	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Constant	2.673	-1.335	6.630	-112.7***	-48.37***	-66.08***
	(21.69)	(14.14)	(10.83)	(21.09)	(12.51)	(11.68)
Observations	2,164	2,164	2,164	2,199	2,199	2,199
R-squared	0.704	0.669	0.694	0.751	0.745	0.684

Source: own

5 Mechanism analysis

The previous empirical analysis pointed out that the green credit subsidy policy promotes corporate green innovation, we now explore the underlying mediating mechanisms, which will help better realize the policy's effect. This article selects external supervision, corporate

reputation, and environmental compliance costs as potential channels. We adopt a two-stage method for mediation mechanism testing and the research model is set as follows.

$$\mathrm{Mediator}_{it} = \delta_0 + \delta_1 \mathrm{Post}_{it} * \mathrm{Treat}_{it} + \delta_2 X_{it} + \gamma_i + \mu_i + \varepsilon_{it} \quad (2)$$

$$\mathrm{Innovation}_{it} = \theta_0 + \theta_1 \mathrm{Post}_{it} * \mathrm{Treat}_{it} + \theta_2 \mathrm{Mediator}_{it} + \theta_3 X_{it} + \gamma_i + \mu_i + \varepsilon_{it} \quad (3)$$

5.1 The mediating role of external supervision

The green credit subsidy policy stimulates firms to invest in green R&D, process innovation, and product upgrading. By introducing external supervision, the policy drives an increase in green innovation output. Specifically, the implementation of this policy attracts green investors to enter the market, strengthening external oversight and positively influencing both the quantity and quality of corporate green innovation. Based on Ge et al. (2025), we use the number of green investors (Investor) as a proxy for external supervision. Existing literature suggests that green financial policies enhance firms' ability to attract green investors (Wang et al., 2025). The regression results are shown in Table 13. The coefficients in Columns (1) and (2) are both positive and statistically significant, indicating that the green credit interest subsidy policy helps green investors identify and invest in firms with environmental value. When such investors enter heavily polluting enterprises, they can establish effective external monitoring mechanisms, promoting corporate green transformation.

5.2 The mediating role of corporate reputation

The green credit subsidy policy is a combination of bank lending and government fiscal subsidies. Therefore, subsidized firms gain government endorsement, which can help enhance the reputation of subsidized firms, increases their media attention, and attract green partners to invest on corporate green innovation activities. Following Edi and Wati (2022), we build a corporate reputation index (REP) using a reputation evaluation framework. By comprehensively considering evaluations from various stakeholders, we select 12 indicators from the perspectives of society, creditors, shareholders, and the firm itself, and use factor analysis to calculate corporate reputation scores, which are then ranked from low to high and assigned values from 1 to 10.

Columns (3) and (4) in Table 13 reveal the mediating role of corporate reputation between the relationship of green credit subsidy policy and green technology innovation. The coefficient of DID in Column (3) is significantly positive, indicating that the implementation of the green credit interest subsidy policy improves the reputation of affected firms, and investors tend to invest in companies with higher reputations and government backing. Existing literature suggests that green credit policies significantly enhance corporate reputation (Wen et al., 2024), while the green credit interest subsidy policy further boosts corporate image and market recognition, amplifying the reputation premium.

5.3 The mediating role of environmental compliance costs

This article measures firms' environmental compliance costs using the Environmental Protection Tax (EPTax). The environmental protection tax encompasses both broad and narrow definitions. Since the narrow definition directly taxes pollutant emissions, it more

accurately reflects firms' actual environmental compliance costs. Following the method proposed by Ye and Mayburov (2025), this paper uses data on the environmental protection tax from 2018 to 2023 and substitutes pollution discharge fees for the period 2010–2017, taking the natural logarithm of these values. The regression results for the environmental compliance cost mechanism are shown in columns (5) and (6) of Table 13. Column (5) shows a significant negative DID coefficient, indicating that the introduction of green credit interest subsidy policies has significantly reduced environmental compliance costs for heavily polluting enterprises, enabling them to allocate more funds toward green technological innovation and the development and implementation of green projects.

Table 13: Mechanism analysis

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	Investor	Innovation	REP	Innovation	EPTax	Innovation
DID	8.130*	2.470***	0.107*	2.225***	-0.0781**	2.617***
	(4.007)	(0.603)	(0.0614)	(0.505)	(0.0267)	(0.658)
Investor		0.0172***				
		(0.00496)				
REP				-0.449***		
				(0.128)		
EPTax						0.388*
						(0.214)
Control variable	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Constant	-572.9***	-33.10**	-42.64***	-56.01***	-3.534***	-47.99***
	(64.33)	(13.97)	(1.659)	(14.68)	(0.862)	(15.23)
Observations	4,834	4,834	4,926	4,926	4,714	4,714
R-squared	0.555	0.713	0.932	0.715	0.946	0.705

Source: own

Conclusion and policy recommendations

Effectively leveraging green finance policies in a scientific manner is crucial for the nation's coordinated advancement of innovation-driven development and the dual carbon goals. This study examines the impact of green credit subsidy policies on green innovation among heavily polluting enterprises from the perspective of green finance. Specifically, using the implementation of green credit subsidies as a quasi-natural experiment, we analyze the effects and mechanisms through which this policy influences green innovation in heavily polluting industries by examining green patent data from listed companies in these sectors between 2012 and 2023 at the firm level. The findings indicate that the implementation of green credit interest subsidy policies significantly promotes green innovation and transformation within

enterprises. Mechanism analysis reveals that these policies enhance green innovation through three channels: strengthening external supervision, improving corporate reputation, and reducing environmental compliance costs. Heterogeneity analysis further shows that the positive effect of green credit interest subsidies on green innovation is more pronounced in state-owned enterprises, large-scale firms, firms located in regions with weaker environmental regulations, regions with higher level of government support, and firms operating in industries with low market concentration.

Based on these findings, the following policy implications are put forward.

Firstly, develop green finance policies according to different countries' conditions and advance interest subsidy policies to empower high-quality green innovation. In practice, green credit interest subsidy policies not only "force" heavily polluting enterprises to undergo green transformation and upgrading by lowering financing costs, but also reconstruct external incentives and constraints to "induce" firms to redirect their limited internal and external resources toward green R&D investment. Unlike previous studies that focused on analyzing individual green finance policies, this paper integrates green finance and fiscal policies into a unified framework to leverage the guiding role of fiscal funds. Therefore, to build a better green financial system, it is essential to strengthen coordination among the Ministry of Finance, central bank, environmental protection agencies, and other relevant departments. This ensures consistent implementation of national and provincial-level green finance policies, and enhance corporate green innovation.

Secondly, fully stimulate enterprises' enthusiasm for green innovation and improve incentive mechanisms. Technological innovation is a key driver of firm green transformation. The government should introduce stronger policy measures to encourage enterprises to invest in technology research and development. On one hand, establish special funds for green innovation to directly support key projects, set up national or regional organizations for green technological innovation, promote collaboration among industry, academia, and research institutions, and accelerate the commercialization of technological achievements. On the other hand, improve intellectual property protection systems to safeguard corporate innovations, which can motivate continuous investment in green technology development.

Thirdly, during the steady advancement of green credit interest subsidy policies, the local government should think considerately about enterprise and regional heterogeneity, enabling targeted policies to optimize the effectiveness of green credit subsidies in promoting innovation. Differences in enterprise ownership structure, scale, and regional government support affect how effectively green credit subsidies drive green transformation. A one-size-fits-all approach to green finance may prevent green innovation from reaching expected quality standards. Therefore, policies should comprehensively consider differences in enterprise size, local financial environment, and regional environmental regulations, setting differentiated thresholds and offering more favorable credit terms for loans to heavily polluting enterprises. Encourage and support the green transformation of small and medium-sized enterprises and non-state-owned enterprises, truly tailoring strategies to local conditions and specific enterprise needs.

Limitations Firstly, our research focuses on Chinese heavily polluting firms. We therefore cannot fully examine the progress and effects of green credit subsidy policies across different countries and significant differences may exist between developed and developing nations.

Secondly, the measure of green innovation in heavily polluting firms could be further improved. Besides patent inventions, we can also consider non-patent innovation outputs, for example process innovation, equipment upgrading and carbon management in supply chain. These measures also demonstrate firms' commitment to improve operational efficiency and green technology. Future research could expand to broader scope and develop a multi-dimensional indicator system.

Finally, firms may disguise their pollution behavior to obtain credit subsidies, while their actual innovation remains limited. This greenwashing practice may weaken the policy's effectiveness. Thus, we need to further identify firms' greenwashing activities in future research.

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Declarations

Competing interests The authors declare no competing interests.

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

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Authors and Affiliations

Xia Liu[1] • Jing Xu[1]

[1] Business School, Suzhou University of Science and Technology, Suzhou 215009, China

*These authors share first authorship.

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