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Green Credit Policy, Analyst Attention, and Corporate Green Innovation

Li Fan and Weidong Xu *

School of Law, Jilin University, Changchun 130000, China; fanli21@mails.jlu.edu.cn
* Correspondence: xuwd@mail.jlu.edu.cn

Abstract: As global sustainability goals gain importance, fostering green innovation has become critical for businesses to reduce environmental impact and enhance sustainability. Green credit policies, which incentivize firms to adopt eco-friendly practices, are a powerful tool in encouraging green innovation. This study examines the impact of green credit policies on corporate green innovation in China, with a focus on high-pollution enterprises, using data from A-share listed companies from 2007 to 2023. The research highlights the significant role of analyst attention in moderating the effectiveness of these policies. The findings show that while green credit policies significantly promote the quantity and quality of green innovation, the impact is further amplified when firms receive higher levels of attention from analysts. The study also finds that larger firms and those with excess cash are more likely to respond positively to green credit policies, as they have the resources to invest in green technologies. This research provides valuable insights into the relationship between green credit policies, corporate green innovation, and the moderating effect of analyst attention, offering practical recommendations for policymakers and businesses aiming to achieve sustainable development goals.

Keywords: green credit policy; green innovation; analyst attention; sustainable development

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1. Introduction

With the continuous growth of the global economy, environmental issues have become a major challenge that urgently needs to be addressed. Problems such as climate change, resource depletion, water scarcity, and pollution are becoming increasingly severe and have had profound impacts on the global ecosystem and socio-economic systems. The United Nations' Sustainable Development Goals (SDGs) explicitly highlight that environmental protection and sustainable resource utilization are among the core issues of global development [1–3]. To address these challenges, governments, businesses, and international organizations worldwide have implemented a series of policy measures aimed at promoting a green economy and environmental protection. However, balancing economic growth with ecological sustainability has become a common goal for all stakeholders [4–6]. In particular, for traditional high-pollution industries, transitioning to a green economic model is not only a significant task for policymakers but also a critical challenge faced by businesses [6–8]. Therefore, promoting green innovation has become an important approach to addressing the environmental crisis, enabling a win–win situation for both the economy and the environment.

Corporate green innovation is driven by various factors. Specifically, technological advancements play a key role in innovations related to green energy (such as solar and wind energy) and environmental protection processes. Bi's research shows that adopting

low-carbon technologies and efficient production processes not only reduces pollution but also enhances the competitiveness of enterprises [9]. Secondly, market demand, particularly consumer preferences for environmentally friendly products, has driven businesses to innovate in green products and services. Song's research indicates that with the growing environmental awareness, consumer demand for electric vehicles and green home appliances has led businesses to increase their investment in research and development (R&D) [10]. On the internal governance side, Abbas mentions that leadership decisions and an innovation-driven culture are crucial for green technology R&D [11], while Cao et al. further emphasize the impact of long-term R&D investments on green innovation. External competitive pressure also plays an important role [12]. Bataineh et al. found that green innovation by peer companies motivates competitors to follow suit, driving the overall green transformation of the industry. Additionally, supply chain management, by promoting green procurement and industry chain collaboration, further drives the expansion of green innovation [13]. Zhao et al. highlights that through collaboration with supply chain partners to jointly develop green technologies, companies not only reduce costs but also enhance the overall sustainability of the industry [14].

Green credit policies, as a mechanism to encourage sustainable business practices, have been gaining attention in recent years. These policies typically involve providing favorable financial conditions, such as lower interest rates or financial subsidies, to firms that meet specific environmental standards. The idea is to incentivize companies to engage in environmentally friendly practices, including green technology research and development (R&D), pollution control investments, and the adoption of green production processes [15].

Several studies have explored the impact of green credit policies on corporate behavior. For instance, Wang et al. (2018) examined how green credit policies in China have provided firms with financial incentives to invest in cleaner technologies, leading to a reduction in pollution and a boost in green innovation [16]. Similarly, Zhang et al. (2019) found that access to green credit significantly lowers the financial barriers for firms to adopt green technologies, especially for small and medium-sized enterprises (SMEs) that may struggle to obtain traditional financing [17]. These findings are supported by the work of Tran, who found that the implementation of green credit policies positively impacts firms' willingness to invest in green R&D and increases their environmental performance, especially in pollution-intensive industries [18].

In addition, some studies have highlighted the role of green credit policies in promoting the green transformation of industries. For example, Negi et al. suggested that green credit policies not only encourage individual firms to adopt cleaner technologies but also foster industry-wide shifts toward more sustainable practices [19]. They argue that firms in industries with more stringent environmental regulations tend to benefit more from green credit policies, as these policies reduce the cost of compliance with environmental standards and promote innovation in sustainable technologies.

However, the effectiveness of green credit policies is not without debate. Some researchers have questioned whether the policies are sufficiently robust to drive significant change, particularly in sectors that are heavily reliant on traditional, high-pollution industries. For instance, Zhang argued that while green credit policies provide short-term financial relief, they may not lead to sustained long-term investment in green technologies unless complemented by other regulatory or market-driven incentives [20].

This study uses enterprise-level data from China to empirically analyze the impact of green credit policies on corporate green innovation through a difference-in-differences (DID) approach, particularly exploring the differentiated effects of green credit policies across different types of enterprises. At the same time, one of the significant innovations of this study is that, in addition to focusing on the direct impact of green credit policies, it also

examines the moderating role of analyst attention in the relationship between green credit policies and corporate green innovation. As a key intermediary in the capital markets, analysts can influence investors' evaluation of a company's environmental performance by focusing on its green innovation activities, which in turn affects the company's financing ability and market reputation. Therefore, this study not only analyzes the driving factors of green innovation from a policy perspective but also introduces the external capital market factor—analyst attention—providing a new perspective for understanding the mechanisms that drive green innovation.

2. Theoretical Analysis and Research Hypotheses

2.1. Green Credit Policy and Enterprise Green Innovation

The Porter hypothesis posits that environmental regulations can simultaneously lead to increased production costs while also driving technological innovation. This hypothesis suggests that while stringent environmental regulations may raise the operational costs of firms, they also encourage innovation by providing firms with incentives to develop new, environmentally friendly technologies. Specifically, green credit policies, which are regulatory mechanisms that provide financial incentives to firms that meet environmental standards, can stimulate technological advancements. The implementation of green credit policies forces companies to reconsider their production methods, adopt cleaner technologies, and optimize resource usage, all of which require significant innovation. Xie et al. and others have highlighted that the intensity of environmental regulation directly affects the degree of green innovation within firms [21]. As the regulatory environment becomes stricter, companies are compelled to develop solutions that comply with these regulations, leading to the creation of more sustainable products and processes [22–24]. The relationship between environmental regulations and green innovation is thus not antagonistic but complementary: regulations push firms toward greener technologies while simultaneously providing opportunities for increased efficiency and competitiveness in the market. According to Steininger and others, enforcing stricter environmental regulations can help balance the trade-off between environmental protection and economic growth [25]. Green innovation, driven by regulatory incentives, not only contributes to environmental sustainability but also increases the firm's competitiveness in the long run. Therefore, green credit policies, as a form of environmental regulation, are expected to induce a transformation in high-pollution industries by fostering technological innovation [26,27]. The theory predicts that companies will innovate not just to comply with the regulations but also to position themselves strategically for future market opportunities. This leads us to hypothesize that green credit policies have a positive impact on green innovation in high-pollution enterprises.

H1: *Compared to non-high-pollution enterprises, the implementation of green credit policies promotes green innovation in high-pollution enterprises.*

2.2. The Moderating Role of Analyst Attention

In addition to the direct effects of green credit policies, this study considers the moderating effect of analyst attention on corporate green innovation. The role of analyst attention in influencing corporate innovation strategies is a subject of debate, with two opposing theories emerging: the information transmission hypothesis and the pressure transmission hypothesis.

The information transmission hypothesis suggests that analysts serve as intermediaries between companies and investors, helping to reduce information asymmetry. Analysts, by providing expert analysis, increase market transparency and ensure that investors are well informed about a company's performance and future prospects [28,29]. In this context,

analyst attention can serve as a positive force, encouraging companies to focus more on innovation, particularly green innovation, which is often less visible and more long-term in nature. Analysts can elevate the profile of green innovation efforts within a firm, making these activities more attractive to investors and thus enhancing the financial incentives for companies to pursue them.

Conversely, the pressure transmission hypothesis presents a contrasting view. This hypothesis suggests that analysts' focus on short-term financial performance and stock price fluctuations can create significant pressure on corporate managers. In an environment where analysts prioritize immediate financial returns, companies may be forced to divert attention away from long-term innovation and sustainability goals to meet short-term market expectations. This pressure can undermine management's willingness to invest in risky but potentially profitable green innovation, as they may perceive such investments as too uncertain in the short term.

However, several studies, including those by Lei et al., have shown that in markets like China, the influence of the pressure transmission hypothesis is somewhat mitigated by the presence of controlling shareholders and state ownership [30]. In China's capital market, where state-owned enterprises (SOEs) are dominant and often guided by national policy priorities, management is less likely to make short-term financial decisions at the expense of long-term innovation. This mitigates some of the pressures that would otherwise influence decision making, as SOE management is more aligned with national environmental and economic goals. Supporting the information transmission hypothesis, Gao et al. found that there is a significant correlation between analyst attention and green innovation performance [31]. The findings suggest that when analysts focus on a company's green innovation activities, they help reduce information asymmetry and promote a greater commitment to green innovation. As such, an increase in analyst attention is expected to positively influence the firm's green innovation efforts, particularly in terms of both the quantity and quality of green patents.

Based on this, the following hypotheses are proposed:

H2a: *Analyst attention positively moderates the impact of green credit policies on corporate green innovation.*

H2b: *Analyst attention negatively moderates the impact of green credit policies on corporate green innovation.*

3. Research Design

3.1. Research Sample and Data Sources

This study selects A-share listed companies from 2007 to 2023 as the research sample. The sample is processed according to the following criteria: abnormally traded listed companies classified as ST (special treatment), *ST (special treatment with risk warning), and PT (particularly traded) are excluded. These classifications are used to identify companies that are facing significant financial difficulties or have been placed under special supervision by regulatory authorities, which may affect their reliability for research purposes. Additionally, samples with missing relevant indicators, such as missing financial performance data (e.g., total assets, revenue, or net income) or incomplete corporate governance information (e.g., board composition or ownership structure), were removed from the sample. After data processing, a total of 51,170 annual observations were obtained. All data were sourced from the Wind and CSMAR databases, which are widely recognized and extensively used in academic and industry research. The Wind and CSMAR databases were selected for several reasons. First, both databases provide comprehensive and accurate financial, market, and corporate governance data for A-share listed companies, making them reliable sources for

analyzing Chinese listed firms. Second, these databases are frequently used in academic studies in China, ensuring that the results are comparable to those of the existing literature. Wind offers a wide range of financial and economic indicators, while CSMAR provides detailed data on corporate governance and firm-level information, which are essential for this study.

3.2. Variable Selection and Measurement

Dependent Variable. This study measures corporate green innovation using the number of green patent applications. The logarithm of the number of green patent applications plus one is taken as the metric for corporate green innovation activities (GPATs), expressed as ln(GreenPatent + 1), where GreenPatent represents the number of green patent applications. Furthermore, the number of green invention patents (GIPATs) is used as an indicator of the quality of corporate green innovation, allowing a comparison between the quantity and quality of green innovation [31,32].

Independent Variable. This study follows the approach of Li et al. by classifying industries based on the environmental and social risk levels outlined in the Key Evaluation Indicators for Green Credit Implementation issued by the former China Securities Regulatory Commission [33–35]. According to the "Key Evaluation Indicators for the Implementation of Green Credit" document issued by the Chinese government in 2012, industries belonging to companies classified as Category A for environmental and social risks are identified as restricted industries for green credit. Specifically, industries under Category A include nuclear power generation, hydropower generation, water conservancy and inland river port engineering construction, coal mining and washing, oil and natural gas extraction, black metal mining and selection, non-ferrous metal mining and selection, non-metallic mineral mining and selection, and other mining industries, totaling nine sectors. When a company belongs to one of these nine industries, it is classified as the treatment group; conversely, when it does not belong to these nine industries, it is classified as the control group. The dummy variable post represents the period before and after the policy implementation, taking the value of 0 before the policy and 1 after the policy.

Moderating Variable. Analyst attention is measured by taking the natural logarithm of the number of securities analysts covering the same listed company plus one [36,37].

Control Variables. The control variables include the debt-to-asset ratio, return on assets (ROAs), return on equity (ROE), total operating cost ratio, operating profit margin, Tobin's Q, book-to-market ratio, total assets (log-transformed), fixed asset ratio, board size (log-transformed), revenue growth rate, cash holdings ratio, and ownership concentration [38–40]. The variable definitions are shown in Table 1.

Table 1. Variable definition table.

Variable Type	Variable Name	Symbol	Definition
Dependent Variable	Green Innovation Quantity Green Innovation Quality	GPAT GIPAT	ln(green patent t + 1) ln(green invention patent t + 1)
Independent Variable	Green Credit Policy	DID	Interaction term (*treat* × *post*)
Moderator Variable	Analyst Attention	AFNUM	Natural logarithm of the number of analysts covering the same listed company plus one

Table 1. *Cont.*

Variable Type	Variable Name	Symbol	Definition
Control Variables	Debt-to-Asset Ratio	Control	Total liabilities/Total assets
	Return on Assets (ROA)		Net profit/Average total assets
	Return on Equity (ROE)		Net profit/Average net assets
	Total Operating Cost Ratio		Operating costs/Operating revenue
	Operating Profit Margin		Operating profit/Operating revenue
	Tobin's Q		Market value of the firm/Replacement cost of assets
	Book-to-Market Ratio		Shareholders' equity/Market value
	Total Assets		Log-transformed total assets
	Fixed Asset Ratio		Fixed assets/Total assets
	Board Size		Log-transformed board size
	Revenue Growth Rate		Revenue growth/Previous year's total revenue
	Cash Holdings Ratio		Net cash flow from operating activities/Total assets
	Ownership Concentration		Shareholding ratio of the largest shareholder

3.3. Model Construction

The difference-in-differences (DID) method is a widely used empirical research technique in econometrics; it is particularly suited for evaluating the impact of policy changes on specific groups. This method estimates the policy effect by comparing the changes before and after the policy implementation between the treatment group (affected by the policy) and the control group (unaffected by the policy). The basic idea is to compare the changes in the treatment and control groups before and after the policy intervention, thereby controlling for unobservable fixed factors that may influence the variable being studied.

In this study, the DID method is used to assess the impact of the green credit policy on corporate green innovation. By dividing firms into high-pollution enterprises (treatment group) and non-high-pollution enterprises (control group) and observing the changes before and after the policy implementation, the specific impact of the green credit policy can be effectively identified.

To investigate the impact of the green credit policy on corporate green innovation and test hypothesis H1, this study constructs a two-way fixed effects model (1).

$$Y_{it} = \beta_0 + \beta_1 DID_{it} + \beta_2 control_{it} + firm_i + year_t + \xi_{it} \quad (1)$$

where Y is the dependent variable representing the number of green innovations by the enterprise, with subscripts i and t denoting the enterprise and the year, respectively. The independent variable (DID) represents the difference-in-differences term. This study classifies industries based on environmental and social risk levels, dividing firms into high-pollution and non-high-pollution enterprises. If the enterprise is a high-pollution enterprise, it is considered the treatment group, with the treatment taking the value of 1; non-high-pollution enterprises are the control group, with the treatment taking the value of 0. The variable post takes the value of 0 before the policy implementation and 1 afterward. The interaction term $(treat \times post)$t measures the effect of the green credit policy on corporate green innovation. β represents the coefficients of the variables, and control denotes the control variables. To ensure the robustness of the empirical results, the model includes both firm fixed effects ($firm_i$) and year fixed effects ($year_t$), with the random disturbance term represented as ξ_{it}.

Furthermore, to examine the moderating role of analyst attention in the impact of the green credit policy on corporate green innovation, and to test hypothesis H2, this study constructs a two-way fixed effects model (2).

$$Y_{it} = \beta_0 + \beta_1 DID_{it} + \beta_2 afnum + \beta_3 didafnum_c + \beta_4 control_{it} + firm_i + year_t + \xi_{it} \quad (2)$$

where Y represents the dependent variable, which is the number of green innovations by the enterprise; DID represents the independent variable, the difference-in-differences term; afnum denotes the moderating variable, analyst attention; $didafnum_c$ represents the interaction term between analyst attention and DID; control represents the control variables; and β denotes the coefficients of each variable. $firm_i$ represents the firm fixed effects, $year_t$ represents the year fixed effects, and ξ_{it} is the random disturbance term.

4. Empirical Results

4.1. Descriptive Statistics

Table 2 provides descriptive statistics for the main variables. The results show that corporate green innovation capabilities exhibit certain characteristics. Specifically, the average values of green innovation quantity (GPAT) and green innovation quality (GIPAT) are only 0.666 and 0.321, respectively, indicating that most companies tend to focus on green invention patents when applying for green patents. Further observation reveals that the standard deviations of GPAT and GIPAT are 1.037 and 0.839, respectively, which suggests significant individual differences in the level of corporate green innovation. These differences may arise from various factors, such as disparities in R&D investment, the maturity of patent technologies, and the extent to which companies prioritize green concepts. Due to the presence of extreme values, winsorization was applied to smooth the sample data before conducting the regression.

Table 2. Descriptive statistics results.

Variables	N	Mean	SD	Min	Max
GPAT	51,170	0.666	1.037	0	6.855
GIPAT	51,170	0.321	0.839	0	6.339
Treat	51,170	0.713	0.351	0	1
Post	51,170	0.667	0.371	0	1
DID	51,170	0.375	0.399	0	1
Analyst Attention	51,170	6.380	9.570	0	75
ROA	51,170	1.166	168.001	−51.95	23,510
ROE	51,170	0.091	6.085	−176.4	713.211
Debt-to-Asset Ratio	51,170	0.593	1.509	−0.195	178.310
Total Operating Cost Ratio	51,170	1.737	71.110	−550.2	9527
Operating Profit Margin	51,170	−0.703	71.560	−9533	552.801
Tobin's Q	51,170	3.111	106.901	0	14,810
Book-to-Market Ratio	51,170	0.617	0.183	0	1.559
Total Assets (log-transformed)	51,170	11.35	1.513	10.840	28.640
Fixed Asset Ratio	51,170	0.151	0.189	0	0.971
Board Size (log-transformed)	51,170	1.173	0.105	0	2.890
Revenue Growth Rate	51,170	8.538	968.901	−1	134,607
Cash Recovery Rate	51,170	0.0369	0.373	−11.061	62.790
Ownership Concentration	51,170	35.090	15.330	0.286	89.990

4.2. Baseline Results

In exploring the impact of the implementation of green credit policies on corporate green innovation activities, this study adopts a comprehensive regression analysis frame-

work. The number of green patent applications is set as the dependent variable, which is then substituted into model (1) for analysis. The regression results are shown in Table 3.

Table 3. Baseline results.

Variables	(1) GPAT	(2) GPAT	(3) GPAT	(4) GPAT	(5) GIPAT
DID	0.515 ***	0.395 ***	0.265 ***	0.372 ***	0.114 ***
	(50.75)	(23.71)	(13.63)	(16.53)	(12.75)
Debt-to-Asset Ratio		−0.061		0.067	0.060 *
		(−1.66)		(1.79)	(2.07)
Return on Assets (ROA)		0.235		0.350 **	0.262 **
		(1.67)		(2.75)	(2.72)
Total Operating Cost Ratio		0.039		0.053	0.050
		(1.23)		(1.56)	(1.79)
Return on Equity (ROE)		0.031		−0.006	−0.019
		(0.65)		(−0.13)	(−0.57)
Operating Profit Margin		−0.160 ***		−0.099 **	−0.071 *
		(−3.77)		(−2.13)	(−1.97)
Tobin's Q		0.017 ***		0.009 **	0.007 **
		(3.06)		(2.37)	(2.05)
Book-to-Market Ratio		0.093 ***		−0.013	−0.036
		(3.36)		(−0.35)	(−1.63)
Total Assets (log-transformed)		0.311 ***		0.237 ***	0.176 ***
		(33.36)		(23.05)	(20.31)
Fixed Asset Ratio		−0.076		0.130 **	0.076
		(−1.67)		(2.63)	(1.93)
Board Size (log-transformed)		−0.170 ***		−0.079 *	−0.027
		(−3.71)		(−2.03)	(−0.71)
Revenue Growth Rate		−0.009		−0.001	−0.002
		(−1.33)		(−0.27)	(−0.37)
Cash Recovery rate		0.096		−0.003	−0.030
		(1.35)		(−0.07)	(−0.76)
Ownership Concentration		−0.005 ***		−0.003 ***	−0.003 ***
		(−9.91)		(−5.91)	(−5.37)
_cons	0.317 ***	−5.999 ***	0.373 ***	−3.790 ***	−3.770 ***
	(15.13)	(−33.37)	(37.73)	(−19.33)	(−17.65)
Control	NO	YES	NO	YES	YES
Firm FE	NO	NO	YES	YES	YES
Year FE	NO	NO	YES	YES	YES
N	51,170	51,170	51,170	51,170	51,170
R-squared	0.744	0.770	0.745	0.771	0.733

Notes: The values in parentheses represent t-values. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

In column 1 (1) of Table 3, the regression results are displayed without including control variables and without fixing the firm and year parameters. Due to the lack of control for the other variables, the results may be influenced by potential factors, making it difficult to accurately reflect the policy effects. Column 2 (2) includes the control variables. Although the firm and year parameters are not fixed, they still reveal some policy impact. This adjustment provides more robustness to the study, but it may weaken the accuracy of the regression. Column 3 (3) presents a two-way fixed effects structure, where no control variables are included, but both the firm and year parameters are fixed. This approach helps reduce potential endogeneity issues and enhances the stability and explanatory power of the regression. Column 4 (4) further develops the previous model by adding control variables while keeping both firm and year fixed in the two-way fixed effects regression.

This combined method not only strengthens the robustness of the model but also improves the precision of the regression analysis. Finally, column 5 (5) replaces the dependent variable with the green innovation quality (GIPAT) in the regression results of column 4.

Based on the data in the above table, it can be observed that whether control variables and fixed effects for firm and year are used separately or in combination, all the DID coefficients are positively correlated at the 1% significance level. This suggests that, compared to non-high-pollution enterprises, high-pollution enterprises have made significant progress in green innovation.

Further analysis of the regression results leads to the following conclusions. First, high-pollution enterprises stand out in their performance. With the advancement of the green credit policy, these enterprises have not only actively applied for green patents in terms of quantity, but the quality of their green patents has also significantly improved. This phenomenon indicates that policy incentives play a significant role in promoting the transformation and upgrading of high-pollution enterprises and driving the green development of industries. Secondly, compared to non-high-pollution enterprises, high-pollution enterprises that have already begun to focus on environmental protection and green innovation have significantly improved both the quantity and quality of their green innovation. This could be because the "Green Credit Guidelines" have restricted high-pollution enterprises' access to financing, causing them to realize the competitive pressures in the market, which leads them to attempt technological green innovation as a means of transformation and upgrading to alleviate financing pressures.

Therefore, it can be concluded that the green credit policy has not only significantly promoted the generation of green technological innovation in high-pollution enterprises, but it has also notably improved the production efficiency of their green technological innovation, thereby facilitating the incremental improvement and quality enhancement of green technological innovation.

5. Robustness Checks

5.1. Parallel Trend Test

Before conducting the event study analysis, it is necessary to verify the parallel trend assumption [41,42]. This assumption requires that, prior to the policy implementation, the green innovation trends of the treatment group (e.g., high-pollution firms) and the control group (e.g., non-high-pollution firms) should be similar. Only after the policy is implemented should a significant difference between the two groups emerge due to the policy's impact.

To test this assumption, this study selects a five-year event window before and after the policy implementation and analyzes the green innovation trend changes of high-pollution and non-high-pollution firms.

The test results are shown in Figure 1. Prior to the policy implementation, there was no significant difference in the green innovation trends between high-pollution and non-high-pollution firms, indicating that the two groups followed parallel trends in green innovation. Therefore, the parallel trend assumption is validated, further enhancing the reliability of the post-policy effect analysis.

5.2. PSM-DID

The impact of green credit policy on corporate green innovation may face endogeneity issues caused by sample selection bias. To address this, we use the PSM-DID method to mitigate endogeneity concerns. The PSM-DID approach combines propensity score matching (PSM) with the difference-in-differences (DID) method, matching high-pollution and non-high-pollution enterprises based on their background characteristics before and

after the policy implementation [43,44]. This method enables a more accurate estimation of the causal relationship of the policy.

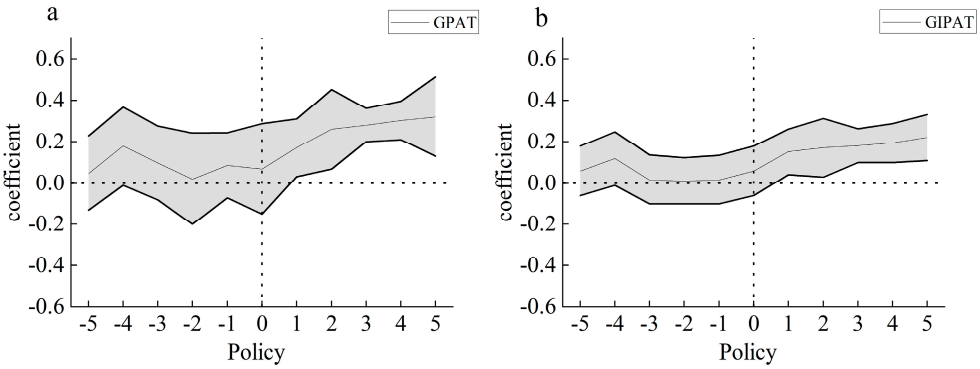

Figure 1. Parallel trend test (**a**,**b**). Note: The shaded area represents the confidence interval.

The test results, shown in Figure 2, indicate that after applying the PSM-DID method, the positive impact of the green credit policy on corporate green innovation remains significant. Specifically, the significant increase in the number of green patent applications (GPATs) and green invention patent applications (GIPATs) after the policy implementation suggests that both the quantity and quality of green innovation have improved. These findings are consistent with the results from the traditional DID model, further validating the effectiveness and robustness of the policy.

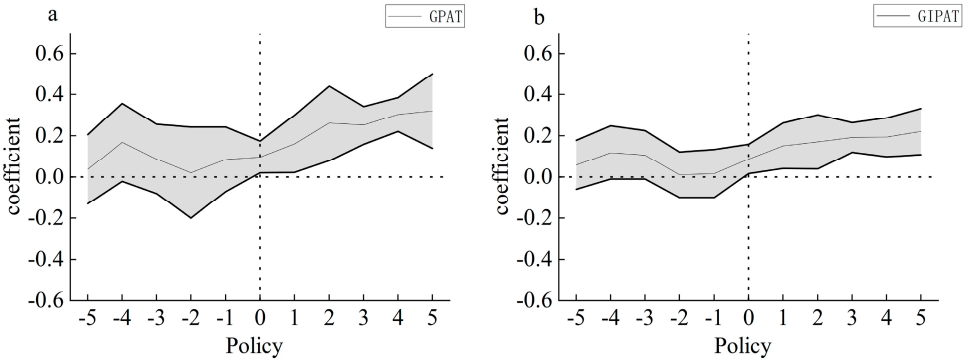

Figure 2. PSM-DID (**a**,**b**).

5.3. Adjusting the Time Window

To exclude the impact of other policies, this study adjusts the time window by narrowing it from the original period (2007–2023) to 2010–2013. During this period, the influence of the green credit policy is more prominent, while potential interference from other policies, such as environmental protection policies, is minimized.

The results, shown in Table 4, present a reanalysis of the changes in green innovation between high-pollution and non-high-pollution firms using the DID model within the adjusted time window. The findings indicate that, even after excluding the influence of other policies, the green credit policy still significantly promoted green innovation in high-pollution firms. Both the number of green patent applications and the number of green invention patent applications significantly increased after the policy implementation, confirming the robustness of the green credit policy.

Table 4. Adjustment time window.

Variables	(1) GPAT	(2) GIPAT
did	0.301 ***	0.109 ***
	(8.14)	(10.75)
Control	YES	YES
Firm FE	YES	YES
Year FE	YES	YES
N	11,040	11,040
R-squared	0.6619	0.6337

Notes: The values in parentheses represent t-values. *** $p < 0.001$.

5.4. Exogeneity Test of Policy Impact

As a quasi-natural experiment, the policy shock is required to be exogenous to the treatment group, meaning that there should be no endogeneity issues between the policy shock and the experimental group. However, considering that firms may anticipate the introduction of the policy and adjust their business behavior in advance, the policy shock may fail to meet the exogeneity requirement.

To address this concern, this study further introduces a robustness check by constructing an interaction term, did_one, and incorporating it into the regression model. Specifically, the did_one variable is defined as a time dummy variable representing the year before the implementation of the smart city pilot policy. As shown in Table 5, the empirical results indicate that the coefficient of did_one is statistically insignificant, while the main policy coefficient remains significantly positive. These findings confirm that the anticipation effect does not confound the policy evaluation, further validating the robustness and reliability of the main conclusions.

Table 5. Exogeneity test of policy impact.

Variables	(1) GPAT	(2) GIPAT
DID	0.222 ***	0.141 ***
	(10.54)	(10.75)
did_one	0.150	0.194
	(1.141)	(1.002)
Control	YES	YES
Firm FE	YES	YES
Year FE	YES	YES
N	51,170	51,170
R-squared	0.6211	0.6034

Notes: The values in parentheses represent t-values. *** $p < 0.001$.

6. Moderating Effect

Considering that the effect of the "Green Credit Guidelines" on corporate green innovation may vary due to differences in analyst attention, this study adds an interaction term between analyst attention and DID in the benchmark regression model to further verify hypothesis H2.

As shown in Table 6, columns (1) and (3) present the regression results of model (4-1) with fixed effects, while columns (2) and (4) reveal the results of model (4-2). These results not only provide empirical evidence in support of the hypothesis but also further confirm the assumptions made earlier. Specifically, the results show that the dummy variable

(DID) is significantly positively correlated with the quantity (GPAT) and quality (GIPAT) of corporate green innovation activities. This means that when enterprises are influenced by the green credit policy, their green innovation behaviors are promoted in terms of both quantity and quality. Additionally, the interaction term of analyst attention plays an important role. It is closely related to the quantity and quality of corporate green innovation and is statistically significant at the 1% level. This finding indicates that the level of analyst attention to a company's information can positively moderate the impact of the green credit policy on corporate green innovation. In other words, when more analysts begin to focus on a company's green innovation activities, this attention may encourage the company to be more proactive in green innovation, thereby improving the overall effectiveness of its innovation activities.

Table 6. Moderating effects.

Variables	(1)	(2)
	GPAT	**GIPAT**
did	0.283 ***	0.186 ***
	(16.18)	(12.32)
$didafnum_c$	0.013 ***	0.013 ***
	(10.55)	(11.84)
AFNUM	0.003 ***	0.002 **
	(3.41)	(2.66)
Debt-to-Asset Ratio	0.068 *	0.066 *
	(2.18)	(2.31)
Return on Assets (ROA)	0.264 *	0.201 *
	(2.18)	(2.13)
Total Operating Cost Ratio	0.052	0.046
	(1.52)	(1.66)
Return on Equity (ROE)	0.005	−0.007
	(0.12)	(−0.24)
Operating Profit Margin	−0.081 *	−0.065 *
	(−2.53)	(−2.40)
Tobin's Q	0.006	0.005
	(1.48)	(1.44)
Book-to-Market Ratio	0.031	−0.012
	(0.81)	(−0.40)
Total Assets (log-transformed)	0.223 ***	0.166 ***
	(18.61)	(16.35)
Fixed Asset Ratio	0.118 *	0.064
	(2.43)	(1.63)
Board Size (log-transformed)	−0.063	−0.011
	(−1.61)	(−0.31)
Revenue Growth Rate	0.001	−0.001
	(0.16)	(−0.01)
Cash Recovery Rate	−0.0036	−0.037
	(−0.06)	(−0.62)
Ownership Concentration	−0.004 ***	−0.003 ***
	(−5.83)	(−5.41)
_cons	−4.411 ***	−3.388 ***
	(−16.80)	(−15.32)
Control	YES	YES
Firm FE	YES	YES

Table 6. *Cont.*

Variables	(1)	(2)
	GPAT	**GIPAT**
Year FE	YES	YES
N	51,170	51,170
R-squared	0.7700	0.7344

Notes: The values in parentheses represent t-values. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

In summary, these regression results strongly validate hypothesis H2a, indicating that, in the context of the green credit policy, analyst attention can serve as an important moderating variable that affects the quantity and quality of corporate green innovation activities. This helps further understand and assess how analysts influence a company's green innovation strategy through their attention to information, and how this strategy is impacted by the external policy environment. For policymakers, this is undoubtedly an important signal, suggesting that when designing relevant incentive measures, they should consider how to better mobilize analysts' enthusiasm to achieve the best green innovation outcomes.

7. Heterogeneity Analysis

7.1. State-Owned Enterprise or Not

To further explore the heterogeneous effects of the green credit policy, this study analyzes the differences in green innovation between state-owned and non-state-owned enterprises. The results are shown in Table 7. According to relevant theories and empirical studies, state-owned enterprises tend to respond better to government policy incentives, particularly benefiting from clear advantages in policy support and financing channels. Therefore, we hypothesize that the green credit policy has a more significant impact on green innovation in state-owned enterprises, while the response from non-state-owned enterprises is relatively weaker [45].

Table 7. Moderating effect regression results.

Variables	(1)	(2)	(3)	(4)
	GPAT	**GPAT**	**GIPAT**	**GIPAT**
DID	0.342 ***	0.043	0.154 ***	0.016
	(16.54)	(1.18)	(12.75)	(1.32)
Control	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
N	17,909	33,261	17,909	33,261
R-squared	0.6919	0.7447	0.6337	0.6370

Note: (1) and (3) are state-owned enterprises, (2) and (4) are non-state-owned enterprises; Notes: The values in parentheses represent t-values. *** $p < 0.001$.

The regression results show that the green credit policy has a significant positive impact on green innovation in state-owned enterprises. Specifically, state-owned enterprises experienced a significant increase in the number of green patent applications (GPATs) and green invention patent applications (GIPATs) after the policy was implemented, indicating that the green credit policy plays a strong role in promoting green innovation in state-owned enterprises. With the support of government policies and guidance, state-owned enterprises are better positioned to leverage the incentives of the green credit policy to drive technological innovation and industrial upgrading.

However, the performance of non-state-owned enterprises after the implementation of the green credit policy is relatively weaker. The regression analysis shows that there was no significant increase in the number of green patents and invention patents filed by non-state-owned enterprises, suggesting that the green credit policy has a limited impact on their green innovation activities. Non-state-owned enterprises may face higher financing costs and have relatively fewer resources and policy support, which could be the reason for their weaker response to green innovation.

7.2. Firm Size

To further analyze the heterogeneous impact of the green credit policy on corporate green innovation, this study also examines the issue from the perspective of firm size. According to resource dependency theory and research on policy implementation effects, larger firms typically have more resources, stronger financing abilities, and greater capacity to adapt to policies. Therefore, we hypothesize that the green credit policy has a more significant impact on the green innovation of large firms [46,47].

First, we classify the sample firms into large and small enterprises based on their size. Large firms are defined according to total asset size. Generally, large firms have stronger competitiveness in capital, technology, market access, and talent, and they are more likely to benefit from government policies. Small firms, on the other hand, may struggle to fully utilize policy support due to limited resources, leading to a weaker response in green innovation activities.

The regression analysis results show that the green credit policy has a significant positive impact on the green innovation of large firms (Table 8). Specifically, the number of green patent applications (GPATs) and the number of green invention patent applications (GIPATs) significantly increased in large firms after the policy was implemented, indicating that large firms are able to effectively leverage the incentives in the green credit policy to drive the research and application of green technologies. This could be due to the fact that large firms have more financial and technological reserves, allowing them to increase investments in green R&D and achieve green transformation under the policy's impetus.

Table 8. Moderating effect regression results.

Variables	**(1)**	**(2)**	**(3)**	**(4)**
	GPAT	**GPAT**	**GIPAT**	**GIPAT**
DID	0.342 ***	0.142 ***	0.174 ***	0.096 ***
	(16.54)	(15.18)	(12.75)	(5.22)
Control	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
N	25,409	25,761	25,409	25,761
R-squared	0.7119	0.7047	0.6837	0.7170

Note: (1) and (3) are big enterprises, (2) and (4) are small enterprises; Notes: The values in parentheses represent t-values. *** $p < 0.001$.

However, while small firms are also affected by the green credit policy, the increase in their green innovation is relatively small, and the changes in their green patent applications are not as significant as those in large firms. This may be because small firms face resource constraints in areas such as capital and technology, making it difficult for them to respond to and absorb the policy benefits as quickly as large firms, resulting in weaker momentum for green innovation.

7.3. Excess Cash or Not

To further explore the heterogeneous effects of the green credit policy, this study analyzes the issue from the perspective of whether firms hold excess cash. A firm's cash flow situation significantly influences its innovation capacity and policy response. Specifically, firms that hold excess cash typically have more financial flexibility, making it easier for them to invest in green innovation [48]. Therefore, we hypothesize that firms holding excess cash will respond more significantly to the green credit policy in terms of green innovation. The results are shown in Table 9.

Table 9. Excess cash or not.

Variables	(1)	(2)	(3)	(4)
	GPAT	**GPAT**	**GIPAT**	**GIPAT**
DID	0.347 ***	0.093 ***	0.151 ***	0.086 ***
	(16.54)	(5.02)	(12.75)	(5.02)
Control	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
N	20,456	30,702	20,456	30,702
R-squared	0.7611	0.7734	0.7320	0.7300

Note: (1) and (3) are firms with excess cash, (2) and (4) are firms without excess cash. Notes: The values in parentheses represent t-values. *** $p < 0.001$.

In this study, surplus cash is defined as the difference between the cash held by a firm and its normal cash requirements. Firms that hold cash amounts greater than the industry average are classified as having surplus cash. We group the sample firms based on whether they possess surplus cash and examine the changes in their green innovation before and after the implementation of the green credit policy.

The regression results show that firms with excess cash experienced a significant increase in both the number of green patent applications (GPATs) and the number of green invention patent applications (GIPATs) after the policy was implemented. This suggests that firms with excess cash have more financial support, allowing them to invest more actively in green technology R&D and to fully leverage the incentives provided by the green credit policy, thereby driving the growth of green innovation.

In contrast, firms without excess cash showed a smaller increase in green innovation after the policy implementation, with no significant changes in their green patent applications. This could be because these firms face tighter financial conditions and are unable to fully utilize the policy resources for technological innovation, resulting in a weaker response to green innovation.

8. Conclusions and Recommendation

8.1. Conclusions

This study investigates the impact of green credit policies on corporate green innovation, focusing on A-share listed companies in China from 2007 to 2023. Using a difference-in-differences (DID) model, the results reveal significant findings regarding the effectiveness of green credit policies in promoting green innovation, particularly in high-pollution enterprises. The study also examines moderating factors, such as state ownership, firm size, and excess cash holdings, which influence the responsiveness of firms to the policy.

The findings confirm that the green credit policy has a significant positive impact on both the quantity and quality of green innovation. High-pollution enterprises, in particular,

showed notable improvements in green innovation after the policy was implemented. This suggests that the policy provides effective incentives for high-pollution industries to adopt greener technologies, resulting in both an increase in the number of green patents and an improvement in the quality of those patents. These findings underscore the policy's role in facilitating the transformation and upgrading of high-pollution enterprises towards greener practices.

Additionally, the study reveals that state-owned enterprises respond more significantly to the green credit policy than non-state-owned enterprises; this is likely due to their better access to financial resources and government support. Large enterprises, with their larger financial and technological reserves, also exhibit more significant improvements in green innovation following the policy implementation. In contrast, small enterprises, particularly those without excess cash, show weaker responses to the policy. This suggests that financial constraints limit the ability of smaller firms to fully capitalize on the incentives offered by the green credit policy, resulting in less substantial improvements in green innovation.

The study also highlights the important moderating role of analyst attention. It finds that when firms attract more attention from analysts, their green innovation activities improve significantly. This suggests that external attention can amplify the effects of the green credit policy, motivating firms to enhance their green innovation efforts.

8.2. Recommendations

The results of this study indicate that green credit policies have a significant positive effect on high-pollution industries and large enterprises, particularly state-owned enterprises. Therefore, policymakers should further optimize green credit policies to enhance their targeting. For high-pollution industries, the guidance of green credit should be strengthened by establishing clear environmental standards and corporate performance evaluation systems to ensure that loan funds are directed toward enterprises genuinely committed to green transformation. Additionally, the government can collaborate with financial institutions to establish dedicated green credit funds, providing long-term, low-interest green loans to eligible enterprises, thereby reducing their financing costs and enhancing their motivation for green innovation.

For small and medium-sized enterprises (SMEs) and non-state-owned enterprises, which often face greater financial pressure and financing constraints, the government should provide more tailored support. For example, a green financing guarantee fund could be established to offer loan guarantees for SMEs lacking sufficient collateral, thereby lowering their financing barriers. At the same time, tax incentive policies could be introduced, such as allowing additional deductions for R&D expenses or granting direct tax reductions for companies meeting green innovation standards, encouraging them to increase investment in green technologies. Furthermore, the government could guide large enterprises to collaborate with SMEs in green innovation, facilitating technology sharing and joint innovation to help smaller firms overcome technological and financial constraints.

This study also finds that analyst attention plays a crucial role in promoting corporate green innovation. Therefore, policymakers can take measures to increase capital market attention to green innovation. For instance, a green enterprise rating system could be established, incorporating green innovation performance into public company disclosure requirements and publishing corporate green innovation reports regularly. These initiatives would raise awareness among investors and analysts about green innovation. Additionally, the government could encourage financial institutions and securities analysts to conduct specialized research on green innovation firms, channeling market resources toward green enterprises and further enhancing the effectiveness of green credit policies.

Moreover, it is recommended to expand the coverage of green credit policies beyond traditional high-pollution industries to other sectors with significant environmental impacts. For example, the manufacturing, transportation, and construction industries are also major contributors to carbon emissions and resource consumption. Extending green credit policies to these sectors would further promote the green transition of the entire economic system. The government can tailor industry-specific green credit standards and incentive mechanisms to ensure that the policy effectively drives green innovation across various sectors.

8.3. Limitations

While this study provides valuable insights into the impact of green credit policies on corporate green innovation, several limitations should be acknowledged. First, the study focuses on A-share listed companies in China, which may limit the generalizability of the findings to other countries or industries. The business environment, regulatory frameworks, and access to green financing may differ significantly across regions, affecting the applicability of the results to non-Chinese contexts.

Second, this study primarily relies on firm-level data from publicly listed companies, which may not fully capture the behavior of smaller firms or those not listed on the stock market. Small and medium-sized enterprises (SMEs), which may face different challenges and incentives in accessing green credit, are underrepresented in the sample. Future studies could include a broader range of firms, including SMEs and privately held companies, to examine how green credit policies affect different types of firms.

Then, while the study examines the moderating role of analyst attention, other external factors, such as market competition, consumer behavior, and industry-specific regulations, may also influence the effectiveness of green credit policies. Future research could explore these factors in greater depth and analyze their interaction with green credit policies to provide a more comprehensive understanding of the drivers of green innovation.

In addition, in analyzing the impact of the green credit policy, this study classified enterprises in the nine heavily polluting industries into treatment and control groups based on industry classification, referring to the policy documents. However, due to limitations in the data, this study did not further determine whether specific enterprises within these industries actually received green credit support. As a result, there may be instances where some control group enterprises also engage in green credit behaviors or have not received green credit but are attempting to obtain it. Due to the lack of detailed information regarding whether specific enterprises received green credit, this study did not account for this variable difference. Future research is recommended to improve this analysis by using more detailed data.

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