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Investigation of the Impact of Green Finance Reform and Innovation Pilot Zones on the Green Innovation of Heavily Polluting Enterprises — Grounded in Empirical Evidence from Listed Companies in Pilot Regions

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Abstract

In 2017, the General Office of the State Council established the initial set of green finance reform and innovation pilot zones in eight locations across five provinces in order to boost the advancement of green finance. Heavily polluting enterprises represent primary targets of green finance policies, and the effects of these policies on such enterprises are significant. The enterprise value indicates the future growth potential of an organization and serves as a primary focus for its stakeholders. Consequently, examining the effects of the establishment of green finance reform and innovation pilot zones on the value of heavily polluting enterprises effectively demonstrates a micro level in order ramifications of this policy and is crucial for assessing the efficacy of green finance initiatives. The present research examines the regulatory structure of pilot zones for environmentally friendly financial and technological advancement, initiated in 2017 as a whole as a quasi-natural test, utilizing listed heavy-pollution companies in A-shares from 2010 to 2023 as the participant data provided. This study employs a DID model to analyze the impact and mechanisms of establishing pilot zones for green finance reform and innovation on the green innovation practices of heavy-pollution enterprises. The findings indicate that the creation of pilot zones for green finance reform and innovation facilitates green innovation among enterprises. The policy of pilot zones for green finance reform and innovation can enhance the level of enterprises' green innovation through increased R&D investment. Subsequent research indicates that, regarding enterprise characteristics, the creation of pilot zones for green finance reform and innovation significantly enhances the green innovation of state-owned enterprises. This paper presents significant empirical evidence supporting the ongoing promotion of the comprehensive and practical development of pilot zones for green finance reform and innovation, aimed at achieving modern development characterized by the harmonious coexistence of humanity and nature.

Keywords

pilot zones for green finance reform and innovation policies, heavy-polluting enterprises, green finance, R&D investment

1. Introduction

In light of the escalating challenges posed by global climate change and contamination of the environment, green finance has emerged as an essential tool in facilitating sustainable economic transition, garnering significant interest from governments and financial institutions worldwide. Environmental finance involves

multiple financial instruments and policies that facilitate environmental protection projects, among which are green credit, green bonds, and green investment funds. The primary aim is to advance the economic system towards a low-carbon, environmentally sustainable model through the strategic allocation of financial resources. China, as the largest developing economy globally, has undertaken significant initiatives to advance green finance reform in recent years. The objective is to improve the financial market's role in resource allocation via policy innovation and institutional development. The creation of Green Finance Reform and Innovation Pilot Zones serves as vital strategy for advancing institutional innovation in green finance, optimizing the Environmental Governance System, and fostering excellent in quality economic development.

High-polluting enterprises represent the primary sources of industrial pollution emissions and serve as the central entities in the transition towards green and low-carbon practices. Traditional high-polluting industries frequently exhibit a lack of motivation for Green Innovation due to constraints such as elevated Environmental Compliance Costs, technological R&D barriers, and inadequate market incentives. Consequently, guiding high-polluting enterprises to augment investment in green technology advancement and research, as well as to assisting them in strengthening their green innovation capabilities through financial mechanisms, has emerged as a significant concern for both academia and policymakers. The Green Finance Reform and Innovation Pilot Zone is designed to enhance financial institutions' support for the Green Industry and increase pressure on High-polluting Enterprises to engage in Green Switching through the implementation of a Green Financial Service System. The specific mechanism and actual impact of the pilot policy on enterprises' Green Innovation require further verification. The degree to which the Green Finance Policy has substantially improved green technological innovation in heavily polluting companies require additional empirical investigation.

Based on the policy practice of the Green Finance Reform and Innovation Pilot Zone, this study selects listed companies in the pilot areas and focuses on examining the impact of the Green Finance Policy on the Green Innovation capabilities of Heavily Polluting Enterprises. By constructing a scientific econometric model, this study will explore whether the policy pilot can effectively encourage businesses to increase their Green Innovation investment and analyze the interaction between enterprise heterogeneity, market mechanisms, and policy effects. The research results will enrich the theoretical framework of green finance and enterprise innovation, and furnish a scientific foundation for policymakers to optimize the allocation of green Financial Instruments and promote the development of industrial enterprises in a green, carbon-free, and sustainable direction.

2. Literature review at home and abroad

2.1 Research on the policies of the green reform and innovation pilot zones

Green Finance represents an emerging practice within the framework of sustainable development in finance, utilizing financial institutions and markets as intermediaries. The strategic allocation of financial resources directs funding to green and low-carbon sectors, promoting resource efficiency and the ongoing enhancement of the ecological environment (He Dexu and Cheng Gui, 2022). The primary objective is to enhance resource allocation within environmental constraints, thereby fostering enterprises' Green Technological Innovation and sustainable development, which in turn facilitates the Green Transformation of the broader economic society. Wei Lili and Yang Ying (2023) employed a mediating effect model and concluded that the Green Credit policy mitigates the misallocation of financial resources, thereby decreasing carbon emissions from enterprises. Geotz (2019) conducted an empirical study on American enterprises, revealing that reduced financing costs can decrease toxic substance emissions and encourage investment in emission-reduction initiatives, thereby positively influencing enterprises' green technological innovation activities.

Research on Green Bonds mainly focuses on aspects such as environmental performance, market reaction, and Enterprise Value. Wu Yuhui and other authors (2022) believe that enterprises issuing Green Bonds will encourage other enterprises in the same industry to implement more measures beneficial to environmental protection. This positive spillover effect will contribute to the achievement of China's dual-carbon goals. Correspondingly, Flammer (2021) believes that the investment direction of Green Bonds has significant

environmental externalities, which can strengthen local ecological civilization construction and improve local carbon emissions. Zerbib (2018), by implementing a matching method on Green Bonds issued from July 2013 to December 2017, found that the environmental protection preference premium of bond market investors is significant, and bond Issuers have the opportunity to benefit from the differences in this asset Items. Ge Chunrui and Han Jun (2023) found that after enterprises issue Green Bonds, they can significantly improve their ESG levels. This promoting effect mainly relies on the enterprises' Green Innovation and the pressure of external supervision.

2.2 Related research on Green Technological Innovation

The Green Technology R&D process of enterprises cannot be separated from the strong financial support of the financial sector. Therefore, financial development has become one of the important influencing factors for enterprises to carry out Green Technological Innovation. It includes various financial development models such as financial agglomeration and Green Finance. Among them, the resource center formed by financial agglomeration will gradually generate a centralized advantage, helping enterprises obtain more innovation resources and increasing the Source of funds for Green Technological Innovation. Studies by existing scholars have shown that financial agglomeration plays a positive role in promoting enterprises' Green Technological Innovation. Song Qinghua and Lin Yongkang (2023) conducted an in-depth study on the impact and mechanism of the capital agglomeration effect brought about by financial development on the Green Technological Innovation of China's Manufacturing industry(Song and Lin, 2023). They found that the financial agglomeration effect has positive externalities, which can improve the availability and convenience of resources for manufacturing enterprises through the aggregation of major innovation resources such as funds, innovative talents, and professional knowledge, thereby enhancing their Green Technological Innovation vitality. In addition to financial agglomeration, the development of Green Finance can also promote enterprises' Green Technological Innovation. Xu Si (2023) took the issuance of China's Green Bonds as an example to study its impact on Green Technological Innovation. They found that green corporate bonds can enhance enterprises' Green Technological Innovation capabilities through two channels: reducing enterprises' Financing Cost and improving the debt structure (Xu et al., 2023). Scholars such as Li and Liu (2021), Zhang and Huang (2023), and Li and Liu (2021) studied the development characteristics of reform pilot zones from the perspective of Green Finance Policy(Qi and Liu, 2023a, Zhang and Huang, 2023, Li and Liu, 2021). They found that implementing active green finance pilot policies can stimulate innovation enthusiasm and activity, channel more funds into Green Technological Innovation, and have a better incentive effect on enterprises with relatively high pollution emission intensity. Yu (2023) also studied the impact of Green Credit policies on enterprises' Green Technological Innovation(Yu, 2023). The study found that after the implementation of the Green Credit Guidelines, both the increase in external commercial credit and the enhancement of internal environmental attention of enterprises significantly promoted Green Technological Innovation. Many other scholars also conducted research from perspectives such as green finance alleviating enterprises' financing constraints (Wang Yulin and Zhou Yahong, 2023), resource effects and supervision effects (Wang and Feng, 2022), etc. They all found that the development of green finance can significantly promote Green Technological Innovation(Wang and Feng, 2022).

From the perspective of government grants and environmental regulations, relevant research points out that under the moderating effect of government grants, the external regulatory pressure faced by enterprises will also increase (Wang et al., 2021). Therefore, enterprises will promote their own Green Technological Innovation by increasing R&D funds and R&D investment (Liu et al., 2024), combining introduction and absorption(Gao et al., 2022), and enhancing the environmental attention of the senior management team (Wu and Hua, 2021). However, the impact of this promoting effect on Heavily Polluting Enterprises shows an inverted U-shaped relationship, which requires the government to fully understand the relevant information of different enterprises before providing grants (Zhang and Zhao, 2022).

Under the moderating effect of environmental regulations, large-scale and highly polluting enterprises will indeed increase R&D investment to promote their own Green Technological Innovation (Han and Ge, 2023). However, it mainly promotes the efficiency of enterprises in the use of fossil energy and the reduction of pollutant emissions at the end, and does not fundamentally reduce Green Innovation in new energy to reduce pollution emissions (Liu and Xiao, 2022). It even leads to a decline in the quality of relevant innovation

activities (Tao Feng et al., 2021), that is, it will increase the possibility of enterprises engaging in greenwashing (Gao et al., 2022, Su and Liu, 2023, Liang, 2025).

2.3 Related research on Green Finance and Green Technological Innovation

Currently, academic research on the relationship between the green finance pilot policy and corporate Green Transformation is insufficient. Compared with single Green Finance Policy and tools such as early Green Credit, the green finance pilot policy has extensive initiatives and rich products. It has the dual characteristics of fiscal Resource Allocation and environmental regulation (Ran and Zhang, 2023). It is the latest comprehensive practice in the construction of the green financial system, and its micro - effects and impact mechanisms on enterprises may differ from other Green Finance Policy. In the early stage, the focus was on the theoretical level. Yan and Wu (2020) put forward suggestions for improving China's green finance reform by sorting out the innovation paths and initiatives of the first batch of pilot zones. In recent years, scholars have analyzed the policy effects from an empirical perspective in relation to the environment and the economy. In terms of the environment, scholars believe that for enterprises, especially high-emission enterprises, the pilot zone policy has a significant carbon emission reduction effect (Fan and Zhang, 2022). In terms of the economy, Jin et al. (2022) argues that the pilot zone policy has significantly curbed the overall development of non-Heavily Polluting Enterprises, but Heavily Polluting Enterprises have successfully obtained "compensatory benefits" through the reverse-forcing mechanism. Ding et al. (2021) found through research that Green Finance Policy promotes sustainable economic growth through industrial structure upgrading. Current researches on the relationship between the pilot policy and enterprise Green Transformation mainly start from the perspective of enterprise Green Innovation. The implementation of the Green Finance Reform and Innovation Pilot Zone policy has significantly promoted the increase in the number of green patents of enterprises within the pilot zone and enhanced the activity of enterprise Green Innovation (Li and Liu, 2021, Qi and Liu, 2023a). Relevant research by other scholars has corroborated this conclusion and supplemented the mechanism of action, such as increasing the scale of Green Credit, alleviating financing constraints (Wang&Zhang, 2022), and strengthening regional environmental constraints (Shi and Zhang, 2024).

2.4 Literature Review

Although previous studies on the development of green finance have yielded relatively rich results, most of these studies mainly focus on single Green Finance Policy areas, such as Green Credit and Green Bonds. However, single Green Finance Policy also has its limitations and may not fully reveal the current situation of the continuously developing and expanding green finance. The establishment of the pilot zones provides an excellent window for this paper to comprehensively and in-depth analyze the effectiveness and impact of the green financial system in actual operations. This perspective not only helps us understand the specific operation of the green financial system but also provides strong support for optimizing and improving relevant policies. Regarding the research on the influencing factors of Green Technological Innovation, the existing literature mainly focuses on environmental regulation policies. Most environmental regulation policies have achieved the expected results in promoting innovation to some extent, but there are significant differences in the effectiveness of policy intensity in promoting innovation. At the same time, due to excessive administrative-order-type interventions in enterprises' Green Innovation by Government Grants and environmental regulations, enterprises face the risk of Greenwashing. That is, enterprises pay more attention to the quantity rather than the quality of Green Innovation, which hinders the construction of the green financial system to a certain extent. Research on the pilot zone policies mainly focuses on the improvement of the policy system and the changes in internal macroeconomic indicators of the pilot zones, such as the quality of economic growth and environmental conditions. However, there is still room for in-depth discussion on the internal logical relationship between the pilot zone policies and enterprises' Green Technological Innovation.

3. Empirical Design

3.1 Variable Selection and Data Sources

3.1.1 Selection of variables

1. Dependent variable

This study examines enterprise green technological innovation, with the dependent variable defined as the level of technological innovation (PAT). Current research primarily assesses this indicator through innovation input and output metrics. There are relatively few defined input indicators, including innovation expenditure, the ratio of innovation expenditure to operating income, and the ratio of innovation expenditure to total assets. In the context of Green Technological Innovation, small and medium-sized enterprises demonstrate traits including extended cycles, elevated risks, and unpredictable outcomes. The likelihood of successfully transforming innovation input into innovation output is minimal. Consequently, utilizing innovation input indicators to assess the technological innovation level of small and medium-sized enterprises may yield results that exceed the actual circumstances. There are several definitive output indicators, such as the number of invention patent applications, operating income, total assets or the increment of intangible assets, and the output value of new products. Among these output indicators, the brief time interval between patent applications and output allows for a more precise measurement of the technological innovation level. Consequently, in this study, the number of patent applications is chosen as the proxy variable. In addition, since the proportion of enterprises with a patent application number of 0 in the research sample is relatively high and there is a relatively obvious end - tail phenomenon, this paper uses the method proposed by Fang Xianming (2023) and Yu Minggui et al. (2016), which is to add 1 to the number of green patent applications and then take the natural logarithm to obtain the required measurement indicator.

2. Explanatory variables

Green Finance Reform and Innovation Pilot Zone policy: The interaction term between the enterprise and the policy is treat x policy. Treat is a dummy variable for enterprises. If it is a Heavily Polluting Enterprises within the pilot zone, it is 1; otherwise, it is 0. Among them, regarding the definition of Heavily Polluting Enterprises, referring to the research of Cao Tingqiu (2021), calculate the sum of the ratios of four types of pollutant emissions in each industry to the total amount of various emissions in the year before the policy shock. If it is greater than 2, it is a heavily polluting industry, and the enterprises within the industry are Heavily Polluting Enterprises. Otherwise, they are non-Heavily Polluting Enterprises. Policy is a dummy variable for the policy. If the region where the enterprise is located is included in the pilot zone, it is set to 1 in the year of inclusion and subsequent years; otherwise, it is 0. The implementation effect is represented by the coefficient of the interaction term.

3. Mediating variables

In terms of R&D investment, this paper measures it by taking the natural logarithm of the amount of the company's R&D investment in the current year, referring to the research of (Liang, 2025).

4. Control variables

As shown in Table 1, to control the characteristics at the corporate level, this paper selects the following as control variables: company size (Size), debt-to-asset ratio (Lev), return on total assets (ROA), operating income growth rate (Growth), equity concentration (Top1), board size (Board), proportion of independent directors (Indep), and CEO duality (Dual).

Table 1: Variables

Variable	Meaning	Name	Measurement Method
Dependent Variable	Green Innovation	lnGP	Natural logarithm of (number of green patent applications + 1)
	Policy Time Dummy	Post	1 for years after policy implementation; 0 otherwise
Independent Variable	Pilot Group Dummy	Treat	1 for HPEs in pilot zones; 0 otherwise
	Policy Interaction	DID	Post × Treat (core explanatory variable)
Mediating Variable	R&D Investment	lnRD	Natural logarithm of annual R&D investment (Liang, 2025)

Control Variables	Firm Size	Size	Natural logarithm of total assets
	Leverage	Lev	Total liabilities / Total assets
	Return on Assets	ROA	Net profit / Total assets
	Revenue Growth	Growth	(Current revenue - Previous revenue) / Previous revenue
	Ownership Concentration	Top1	Shares held by the largest shareholder / Total shares
	Board Size	Board	Natural logarithm of number of board directors
	Independent Director Ratio	Indep	Number of independent directors / Total board directors
	CEO-Chairman Duality	Dual	1 if CEO and chairman are the same person; 0 otherwise
Fixed Effects	Year Fixed Effects	year	m-1 year dummy variables (to avoid dummy variable trap)
	Industry Fixed Effects	ind	n-1 industry dummy variables (to avoid dummy variable trap)

Note: Post and Treat single items are not included in the model because the years and industries will be controlled in the model, so the impact of absorbed single items is no longer included.

3.1.2 Data sources

This time, the data of all A-shares heavily polluting listed companies were selected. The data sources are Wind Database, CSMAR Database, and CNRDS Innovation Database. All these data sources are relatively authoritative websites, which ensures the credibility and feasibility of the data.

The conclusions of the empirical analysis are derived from general data, owing to the specific characteristics of certain enterprises. Hence, certain anomalous data were excluded, including samples from enterprises experiencing financial distress, such as Special Treatment companies, ST enterprises, and delisted companies. Moreover, organizations within the financial sector possess distinct characteristics inherent to their operations. The aforementioned special enterprises were excluded. In cases of missing data, only the incomplete samples will be excluded, preserving the integrity of the entire dataset to avoid significant information loss. Consequently, unbalanced panel enterprise data are typically utilized for research purposes.

A sample period of 14 years, spanning from 2010 to 2023, was utilized. A total of 1,320 enterprises classified as Heavily Polluting Enterprises were included in the analysis, with a sample size of 11,724 data points entered into the model. Due to the substantial data volume in this study, winsorization is necessary to mitigate the potential negative effects of outliers on the model outcomes. The winsorization parameter is established at 1% for both upper and lower tails, indicating that data within the upper and lower 1% are classified as outliers and will be adjusted to fit within the normal range.

3.2 Model construction

Based on the dummy variables set in this paper, variables and models are constructed according to the principle of DID model, and corresponding effect controls are added to estimate the double fixed-effects model:

$$\ln Gp_{it} = \alpha_0 + \alpha_1 post_t + \alpha_2 Treat_i + \alpha_3 post_t * Treat_i + C_v + \mu_i + v_t + \varepsilon_{it} \quad (3\text{-}1)$$

The aforementioned is the intercept term. The influence coefficient of DID ispresented. A positive value indicates that the implementation of the DID policy will result in an increase in Y. A negative value indicates that the policy's implementation will result in a decrease in Y. Comparable conclusions may be drawn for the other variables. The random error term encompasses the effects of additional variables not addressed in this study. To account for the double fixed effects of year and industry, both the year effect and individual effect are incorporated. The table previously mentioned has presented the control variables, while the core explanatory variables are emphasized in this model design. CV denotes the control variables.

3.3 Analysis of Empirical Results

3.3.1 Descriptive statistical analysis

As shown in Table 2, it measures the variables included in the model in this paper. Meanwhile, understand the situation of all variables, including their fluctuation ranges, degrees of fluctuation, and average values, so as to determine whether the data processing in this paper is reasonable. Next, the "sum" command in Stata software is used for analysis as shown below:

Table 2: Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
lnGP	11724	0.7670	1.0810	0.0000	4.3944
Post	11724	0.6279	0.4834	0.0000	1.0000
Treat	11724	0.2656	0.4417	0.0000	1.0000
DID	11724	0.1738	0.3790	0.0000	1.0000
lnRD	11724	16.4929	5.0475	0.0000	21.6868
Size	11724	22.3414	1.3134	20.0637	26.1093
Lev	11724	0.4049	0.2042	0.0541	0.8845
ROA	11724	0.0470	0.0634	-0.1699	0.2204
Growth	11724	0.1477	0.3338	-0.4787	1.7582
Top1	11724	0.3487	0.1478	0.0908	0.7319
Board	11724	2.1387	0.1940	1.6094	2.6391
Indep	11724	0.3719	0.0503	0.3333	0.5556
Dual	11724	0.2731	0.4456	0.0000	1.0000

Note: The coefficient of variation mentioned below is the standard deviation divided by the mean. The higher this value, the greater the fluctuation.

The number of samples in each case is 11,724, indicating that there is no missing data as it has been processed in advance. The mean of lnGP is 0.7670, with a fluctuation range between 0.0000 and 4.3944. The fluctuation range is relatively small. The standard deviation is 1.0810, which is greater than the mean, resulting in a relatively high coefficient of dispersion. The samples in the experimental group account for 26.56%. The samples after the policy implementation account for 62.79%. The samples in the experimental group after the policy implementation account for 17.38%. The mean of the asset - liability ratio is 0.4049. Both ROA and Growth have relatively large fluctuations. The samples with the combination of two positions account for 27.31%.

3.3.2 Correlation analysis

Based on the t-test of correlation analysis (if the program automatically generates asterisks), the measure of correlation analysis can first ascertain whether the association between variables is significant. Additionally, the sign of the correlation coefficient can be used to determine the direction of the correlation between variables. The variables change in the same direction if it is positive; if not, they change in the opposite direction. Furthermore, the correlation increases with the correlation coefficient's absolute value. Correlation, however, merely refers to the link between two variables. As a conclusion, it simply acts as a foundation for first assessment.

Table 3: Correlation analysis

Variables	lnGP	Post	Treat	DID	lnRD	Size	Lev	ROA	Growth	Top1	Board	Indep	Dual
lnGP	1												
Post	0. 1689***	1											
Treat	0.0062	0.0330***	1										
DID	0.0776***	0.3531***	0.7627***	1									
lnRD	0.2005***	0.2037***	0.0700***	0. 1093***	1								
Size	0.5759***	0.0865***	-0.0594***	-0.0143	0. 1410***	1							
Lev	0.2606***	-0. 1043***	-0.0400***	-0.0469***	-0. 1080***	0.4709***	1						
ROA	-0.0106	0.0359***	0.0550***	0.0459***	0. 1079***	-0.0508***	-0.4572***	1					
Growth	0.014	0.0096	0.0064	0.0025	0.0073	0.0144	-0.0074	0.3028***	1				
Top1	0. 1705***	-0.0877***	-0.0230**	-0.0353***	0.0313***	0.2496***	0.0687***	0.0887***	0.0117	1			
Board	0. 1616***	-0. 1518***	-0.0514***	-0.0962***	-0.0237**	0.2883***	0. 1798***	-0.0254***	0.0056	0.0259***	1		
Indep	0.0049	0.0700***	0.0197**	0.0392***	-0.0068	-0.0019	-0.0068	-0.0240***	-0.0115	0.0288***	-0.5190***	1	
Dual	-0. 1503***	0.0869***	0.0652***	0.0851***	0.0824***	-0.2172***	-0. 1468***	0.0700***	0.0355***	-0.0629***	-0. 1568***	0.0546***	1

*Note: *, **, and *** indicate passing the test at the significance levels of 10%, 5%, and 1%, respectively. The more asterisks there are, the higher the probability of passing the test.*

As shown in Table 3, at the 1% significance level, the correlation coefficient of 0.0776 between DID and lnGP is significant. Green finance will result in more green patents, which would support the notion in the short term. However, because correlation analysis is inaccurate, it is necessary to adjust for other factors in order to evaluate the link between variables more precisely. For verification, further regression analysis is therefore necessary. The correlation coefficients from the second to the last column, with the exception of the first column, have a maximum absolute value of 0.4709, which is below the crucial value of 0.8. As a result, regression analysis can be performed without interference because the model's multicollinearity is not severe.

3.3.3 Multicollinearity test

The VIF test is a more precise test to verify whether there is a high degree of multicollinearity in the model. This method fits each explanatory variable with the remaining non-explained variables. As shown in Table 4, as long as the R-squared of the fit is not higher than 0.9, the VIF value will be less than 10, which means that a certain degree of collinearity has not been reached. If it is higher than 10, the variables causing high multicollinearity need to be removed for analysis.

Table 4: Model VIF Test

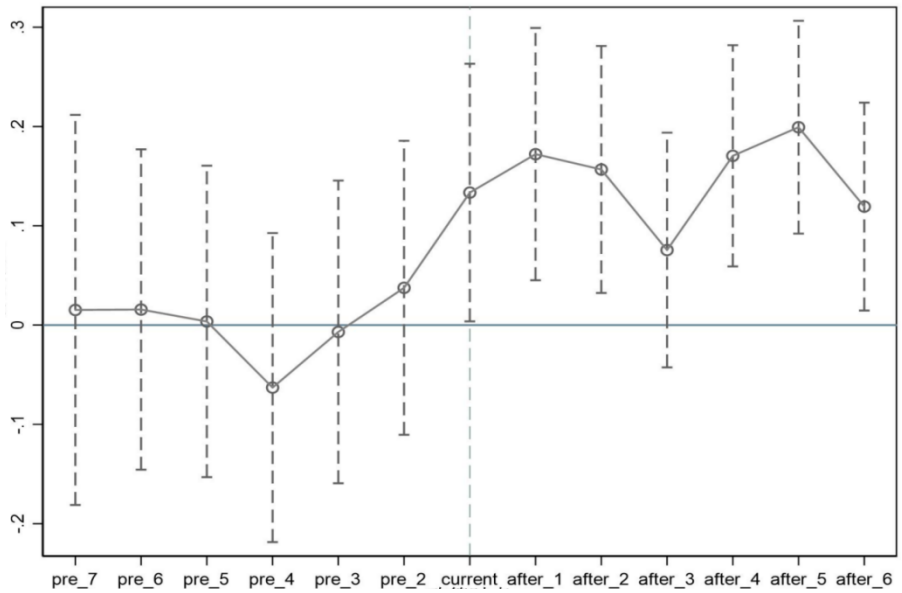
Variable	VIF	1/VIF
Lev	1.7500	0.5725
Board	1.5700	0.6363
Size	1.5700	0.6388
ROA	1.5100	0.6612
Indep	1.4200	0.7057
Growth	1.1300	0.8827
Top1	1.0800	0.9226
Dual	1.0700	0.9335
DID	1.0200	0.9810
Mean VIF	1.3500	

Lev's VIF value is 1.7500, and the reciprocal of its VIF value is also greater than 0.1, meeting the standard. The remaining variables all meet the standards of having a VIF less than 10 and the reciprocal of the VIF greater than 0.1. Therefore, it is further verified that the multicollinearity of the model is not severe and will not be significantly interfered with.

3.3.4 Parallel trend test

Since the prerequisite for the difference-in-differences method is to pass the parallel trend test, each time point is set as a dummy variable, which is interacted with the dummy variables of the experimental group and the control group, and regression analysis is conducted. The coefficient size of each point is examined, and a graph is plotted, just as shown in Fighre 1. Taking a time point before the policy as the control group, if the confidence interval of each time point before the policy includes 0, it indicates that there is no significant difference between the experimental group and the control group before the policy. This means that the subsequent DID results will not be affected by the differences between the experimental group and the control group before the policy, and the results can divest the impact brought by this factor.

Figure 1: Parallel Trend Test Chart



Note: pre_ refers to the period before the policy, current refers to the period when the policy is in effect, and after_ refers to the period after the policy.

Before the policy, the confidence intervals from pre_7 (the 7 periods before the policy) to pre_2 all include 0, which means there is no significant difference in the values of the explained variables between the experimental group and the control group. However, the dotted lines in the current period and later periods of the policy do not include 0. Therefore, it indicates that the policy has brought about a certain impact.

3.3.5 Analysis of Benchmark Regression Results

This study controls for the impacts brought by year effects and industry effects because the explained variables vary across different years and industries. The results obtained by using the two-way fixed effects model are also more accurate, as shown in Table 5.

Table 5: Model estimation

VARIABLES	(1) lnGP	(2) lnGP
DID	0.1009***	0.1474***
Size	(3.7924)	(6.5249) 0.4283***
Lev		(52.5598) 0.0393
ROA		(0.7336) 0.2053
Growth		(1.3199) -0.0117
Top1		(-0.4457) 0.3416***
Board		(5.9447) 0.1685***
Indep		(3.1944) 0.3654*
Dual		(1.9370) -0.0996***
Constant	0.7496***	(-5.3515) -9.4386***
Year Fixed Effect	(71.6525) Control	(-46.6301) Control

Industry Fixed Effect	Control	Control
Observations	11,722	11,722
Adj R-squared	0.1168	0.3668
F	14.3824***	516.2528***

*Note: *, **, and *** indicate passing the test at the significance levels of 10%, 5%, and 1%, respectively. The more asterisks, the higher the probability of passing the test. The values in parentheses are t-values.*

The benchmark regression model's results indicate the following conclusions. Only explanatory variables and double fixed effects are included in the first column above, which displays the results without control variables. The results with control variables included are displayed in the second column. The outcomes of the primary explanatory variables are comparatively significant whether or not control factors are included. The goodness-of-fit improves a fair amount after control variables are included, reaching 36.87%. For a comparatively big amount of data, the goodness-of-fit is in a rather tolerable state while not being high. The entire model passes the test, as indicated by the F-test value of 516.2528. The primary explanatory variable DID's influence coefficient, when examined separately, is 0.1474, and it passes the test at the 1% significance level, indicating a positive link between DID and lnGP-that is, that the policy will raise lnGP. There are no discernible impacts of the control variables Lev, ROA, and Growth. lnGP will rise in response to increases in Size, Top1, Board, and Indep. Businesses that combine the two roles have a lower level of green innovation.

3.4 Robustness test

3.4.1 One-period lagged explanatory variable

The robustness test is a test used to assist in verifying whether the results of regression analysis are stable. That is, through a method, if the results of the core explanatory variables are consistent with those in the previous text, it indicates that the results are non - random and credible. A robustness test is conducted by lagging the policy by one period, and the verification is as follows:

Table 6: Robustness test

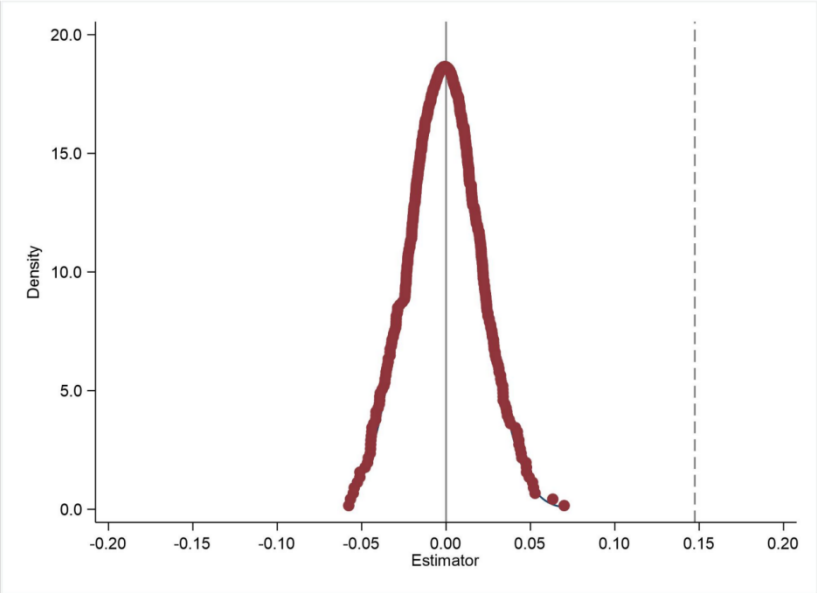
VARIABLES	(1) lnGP	(2) lnGP
L.DID	0.1081*** (3.5753)	0.1539*** (6.0005)
Size		0.4409*** (48.7990)
Lev		0.0425 (0.7126)
ROA		0.0736 (0.4217)
Growth		0.0008 (0.0280)
Top1		0.3628*** (5.6942)
Board		0.1987*** (3.4028)
Indep		0.4971** (2.3913)
Dual		-0.1127*** (-5.4667)
Constant	0.8051*** (70.3678)	-9.8216*** (-43.9002)
Year Fixed Effect	Control	Control
Industry Fixed Effect	Control	Control
Observations	10,164	10,164
Adj R-squared	0.1177	0.3691
F	12.7830***	451.7346***

*Note: *, **, and *** indicate passing the test at the significance levels of 10%, 5%, and 1%, respectively. The more asterisks there are, the higher the probability of passing the test. The values in parentheses are t-values.*

3.4.2 Placebo test

In the case of a one-period lagged variable, the regression coefficient of DID on lnGP is 0.1539, which is still significant. That is, the direction of the impact is consistent with the significance of the impact. Therefore, the results are non-random and reliable. As shown in Figure 8, it can be seen that the coefficients fluctuate around 0. Therefore, the placebo test is passed.

Figure 2: Placebo test



3.5 Heterogeneity analysis

As the name suggests, the heterogeneity analysis examines whether the impact of the explanatory variables on the explained variable varies with the selection of different samples. The samples are divided into state-owned and non-state-owned enterprises according to the nature of industry enterprises to understand whether there are significant differences in the impacts of the explanatory variables between the two groups.

Table 7: Heterogeneity analysis

VARIABLES	State-owned lnGP	Nonstate-owned lnGP
DID	0.3313***	0.1413***
	(-6.5038)	(-5.9771)
Size	0.5309***	0.2980***
	(-38.2929)	(-29.0026)
Lev	-0.2662	0.3289***
	(-2.7416)	-5.295
ROA	-0.0634	0.5307***
	(-0.2024)	(3. 1472)
Growth	0.0565	-0.0198
	(1. 1527)	(-0.6749)
Top1	0.2200**	0.0825
	(2. 1050)	(-1.2087)
Board	0. 1756**	-0.0546
	-1.9885	(-0.8426)
Indep	0.7548**	-0.5481**
	-2.3957	(-2.3820)
Dual	-0.1745***	-0.064***
	(-3.7205)	(-3.3456)
Constant	-11.7195***	-5.8469***
	(-35.9988)	(-21.3494)
Year Fixed Effect	Control	Control

Industry Fixed Effect	Control	Control
Observations	4,418	7,303
Adj R-squared	0.4594	0.2051
F	262.8171***	154.8007***

As shown in Table 7, the coefficient of the state-owned DID is 0.3313, with three asterisks, indicating a significant state. The influence coefficient of non-state-owned enterprises is 0.1413, with two asterisks, also indicating a significant state. Moreover, the influence coefficient of state-owned enterprises is higher, which means that the positive impact of the group policy on enterprises' Green Innovation is more obvious.

4. Testing of the Influence Mechanism of Green Finance Innovation Policies on Heavily Polluting Enterprises' Green Innovation

4.1 Introduction of the mediating effect model

First, based on the dummy variables set in this paper, variables and models are constructed according to the principle of DID model, and corresponding effect controls are added to estimate the double-fixed model:

$$lnGp_{it} = \alpha_0 + \alpha_1 post_t + \alpha_2 Treat_i + \alpha_3 post_t * Treat_i + C_v + \mu_i + v_t + \varepsilon_{it} \quad (4\text{-}1)$$

Second, to verify the mediating role of R&D investment in the impact of Green Finance innovation policies on the Green Innovation of Heavily Polluting Enterprises, this paper introduces R&D investment as a mediating variable and constructs a research model of the impact of Green Finance innovation policies on R&D investment as follows:

$$lnRD_{it} = \alpha_0 + \alpha_1 DID_{it} + Cv + \Sigma\, year + \Sigma\, ind + \varepsilon_{it} \quad (4\text{-}2)$$

Finally, this paper constructs a research model of the impact of Green Finance innovation policies and R&D investment on the Green Innovation of Heavily Polluting Enterprises:

$$lnGp_{it} = \alpha_0 + \alpha_1 DID_{it} + \alpha_2 lnRD_{it} + Cv + \Sigma\, year + \Sigma\, ind + \varepsilon_{it} \quad (4\text{-}3)$$

The impact coefficient of DID, or intercept term, is shown above. Whereas a negative value suggests that the DID policy's adoption will result in a reduction in Y, a positive value suggests that the policy's implementation will raise Y. The other variables can be inferred similarly. The impact of other factors not covered in this work is then included in the random error term. The year effect and individual impact are introduced in order to control the double fixed effects of industry and year. The primary explanatory factors are highlighted in this model design because the control variables have already been shown in the preceding table. The control variables are represented by CV.

4.2 The mediating effect of R&D investment

According to the three-step method of the mediating effect, the results of the above benchmark regression analysis are the first step of the mediating effect. Next, the second and third steps of the analysis are carried out, as shown in Table 8.

Table 8: The mediating effect analysis

VARIABLES	(1) lnRD	(2) lnGP
DID	0.5469***	0. 1285***
	-5.0635	-5.7615
lnRD		0.0345***
		-18.0962
Size	1.2795***	0.3841***
	-32.839	-45.7286
Lev	-2.2004***	0. 1153**
	(-8.5830)	(2. 1737)
ROA	2.0310***	0.1351
	-2.731	-0.8808
Growth	-0.1033	-0.0081

	(-0.8229)	(-0.3141)
Top1	1.9205***	0.2753***
	-6.9898	-4.847
Board	0.4237*	0. 1538***
	-1.6801	-2.9571
Indep	-2.6952***	0.4584**
	(-2.9880)	-2.4631
Dual	0.5321***	-0. 1180***
	-5.979	(-6.4168)
Constant	-12.0942***	-9.0210***
	(-12.4949)	(-44.8866)
Year Fixed Effect	Control	Control
Industry Fixed Effect	Control	Control
Observations	11,722	11,722
R-squared	0.3367	0.3859
F	176.3762***	510.3542***

In the second step of the mediating effect, the coefficient of DID on lnRD is 0.5469, which means that an increase in the policy will lead to an increase in R&D investment. In the third step of the mediating effect, both DID and lnRD have a significant promoting effect. That is, the policy will promote corporate Green Innovation by promoting an increase in R&D investment, indicating that the mechanism holds.

5. Conclusions and Recommendations

5.1 Main Conclusions

The Green Finance Reform and Innovation Pilot Zone is essential for advancing the "dual carbon" goal and notably contributes to China's high-quality economic development. This study utilizes a quasi-natural experiment from the Green Finance Reform and Innovation Pilot Zone, analyzing 1,320 heavily polluting enterprises listed on the Shanghai and Shenzhen A-shares from 2010 to 2023, which lead to a total of 11,724 sample data points. The difference-in-differences method is employed to investigate the effects of the Green Finance Policy on the green innovation of these enterprises. The conclusions of the research are as follows: The creation of the Green Finance Reform and Innovation Pilot Zone strongly supports the Green Transformation of enterprises, a finding that remains valid following various robustness tests. Furthermore, mechanism analysis indicates that the establishment of the Green Finance Reform and Innovation Pilot Zone can facilitate the Green Transformation of enterprises through the improvement of their R&D investment. The heterogeneity analysis results indicate that in state-owned enterprises, the impact of the Green Finance Reform and Innovation Pilot Zone on enterprise Green Innovation is more pronounced. This suggests that policy guidance is crucial in advancing the Green Transformation of enterprises, particularly within state-owned enterprises, where it can more effectively boost the motivation for Green Innovation.

5.2 Policy Recommendations

The research findings indicate that the establishment of the Green Finance Reform and Innovation Pilot Zone has substantially facilitated the green transformation of enterprises, with a pronounced enhancement of this effect through increased R&D investment, particularly in state-owned enterprises. This study presents targeted recommendations for enterprises, government, and financial institutions to optimize the Green Finance Policy, improve enterprises' Green Innovation capabilities, and advance the sustainable development of industries.

The government should enhance the specificity of the Green Finance Policy and improve institutional guarantees. The study indicates that the creation of the Green Finance Reform and Innovation Pilot Zone significantly enhances the Green Transformation of enterprises. Consequently, the government ought to enhance the policy design of the pilot zone to guarantee the sustainability and replicability of the policies. Simultaneously, it is essential to provide more comprehensive industry guidance to promote ongoing investments by enterprises in Green Innovation. A scientific policy evaluation mechanism should be established to optimize data-driven policies, ensuring that the Green Finance Policy effectively addresses

various types of enterprises and mitigates resource misallocation and policy blind spots associated with a uniform approach.

Secondly, enterprises should proactively augment investment in research and development and optimize their Green Technological Innovation competencies. Research has found that the Green Finance Reform and Innovation Pilot Zone can promote Green Transformation by increasing enterprises' R&D investment, indicating that R&D investment is an important intermediary path for enterprises to achieve Green Transformation. Therefore, enterprises should fully utilize policy dividends, enhance expenditure on environmentally friendly technology research and development, green product development, and low-carbon production process transformation to promote technological upgrading. At the same time, enterprises can strengthen industry-university-research cooperation, jointly build Green Innovation platforms with universities and research institutions, and accelerate the industrial application of green technologies to enhance their market competitiveness.

Finally, financial institutions should optimize the green financial product system and enhance the precision and sustainability of financial support. As an important implementation subject of Green Finance Policy, financial institutions should innovate green Financial Instruments based on the green development needs of different enterprises, such as Green Bonds, Green Credit, carbon trading financing, etc., to provide diversified financing channels. In addition, financial institutions should strengthen the dynamic monitoring of the performance of enterprises' Green Transformation, build a differentiated Green Credit evaluation system, and provide more policy-based financial assistance to enterprises with high R&D investment and strong Green Innovation capabilities to form positive incentives and further promote the process of enterprises' Green Transformation. Financial institutions can cooperate with government departments to provide customized green financial products for state-owned enterprises and optimize the green financing mechanism to promote the effective implementation of Green Finance Policy.

5.3 Future Outlook

Against the backdrop of the global Green and Low-carbon Transformation trend, green finance, as an important policy tool to promote enterprises' Green Transformation, will see its role further deepened and expanded. Based on the findings of this study, there are still many directions worthy of exploration in the future regarding the impact of the Green Finance Reform and Innovation Pilot Zone on enterprises' Green Transformation. Meanwhile, policy optimization, corporate practices, and financial innovation also need continuous improvement to achieve more efficient and sustainable green development goals.

First, future research can further explore the mechanism of action and long-term impact of Green Finance Policy. Although this study finds that the Green Finance Reform and Innovation Pilot Zone can promote Green Transformation by increasing enterprises' R&D investment, future research can still delve into the specific paths of enterprises' Green Innovation, such as green patent output, green technology application, and green supply chain collaboration. In addition, the long-term effects of Green Finance Policy need further verification. Future research can combine data over a longer time span to explore the persistence of policy impacts and possible dynamic evolution trends.

Secondly, in-depth research is still needed on the regional adaptability and differentiated optimization of Green Finance Policy. There are significant differences in the economic growth levels, industrial structures, and environmental regulatory intensities among different regions. The implementation effects of Green Finance Policy may vary depending on regional characteristics. Therefore, in the future, it is feasible to include regional heterogeneity elements to investigate the applicability of the Environmental Finance Policy across different regions and propose more precise policy optimization paths to improve the effectiveness and adaptability of the policy.

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Conflicts of Interest

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