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The Impact of ESG Ratings on Enterprises' Green Innovation Capability: An Empirical Study Based on Staggered Difference-in-Differences（Staggered DID）

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Abstract

Based on a Staggered Difference-in-Differences（Staggered DID） model, this paper empirically examines the impact of ESG ratings on corporate green innovation capability and its mechanism. The study takes Chinese A-share listed companies from 2009 to 2023 as a sample, and uses the first announcement of ESG ratings by SynTao Green Finance as an exogenous shock. The study finds that ESG ratings significantly enhance the green innovation capacity of enterprises, increasing the total green innovation by 12.19% on average, and the promotion effect on green invention patents is larger than that on green utility model patents. Moreover, the robustness of the results was verified by parallel trend test, placebo test, and changing the sample interval. Heterogeneity analysis shows that the promotion effect is more significant in larger firms. Further mechanism tests reveal that financing constraints and supply chain discourse are key moderating variables: financing constraints weaken the positive effect of ESG on green innovation, and supply chain discourse strengthens the positive effect of ESG on green innovation. This study provides empirical evidence to understand how ESG ratings drive corporate green innovation by alleviating information asymmetry, strengthening reputational monitoring and optimising resource allocation, and provides insights for companies to optimise ESG strategies, governments to improve green financial policies and promote industry chain synergies.

Keywords

ESG rating, green innovation, Staggered DID, financing constraints, supply chain discourse

1. Introduction

With the rapid development of economy and society, the concept of sustainable development is deeply rooted in people's hearts, and green finance and green development have become one of the important environmental protection concepts generally pursued by all countries. Countries have introduced various policies to promote the sustainable development of the financial industry. The European Union issued the Sustainable Finance Disclosure Regulation in 2021, which requires capital management institutions to disclose ESG risks, covering 100% of financial institutions in Europe; China's green financial system has accelerated the construction of the green financial system since 2015, forming a multi-level framework with national strategies as the lead, special policies as the core, and supporting measures as support. 2023, the implementation of the "Administrative Measures for the Disclosure of Environmental Information of Enterprises in accordance with Law" is mandatory. Listed companies issuing debt enterprises to disclose environmental information financial instruments to disclose the use of green loans carbon emission reduction support tools. However, these mandatory government measures are

prone to greenwash behaviour. In order to prevent the increase of greenwash, the government requires third-party organisations to be responsible for the authenticity of green project certification and assessment reports, and encourages enterprises to disclose ESG-related information. 2025 will be a key point for the construction of an ESG ecosystem. The Ministry of Finance has issued disclosure guidelines on climate issues, providing norms and guidance for corporate disclosure of climate-related information. The continued increase in policy has made ESG ratings increasingly important.

ESG environmental responsibilities require companies to reduce carbon emissions, conserve energy, and protect ecosystems. However, short-term pollution control measures cannot ensure a company's long-term survival and development. When companies realize that end-of-pipe pollution treatment alone cannot meet increasingly stringent environmental requirements, their green innovation capabilities become the key to breaking the deadlock. To become true leaders in sustainable development, companies must further transform environmental constraints into innovation opportunities, which is the core value of green innovation capabilities. According to Su et al. (2024), current ESG research primarily focuses on: the mechanisms through which ESG influences corporate value, such as Yao and Jiang (2023) pointing out that ESG can alleviate financing constraints and drive corporate innovation; measurement and evaluation mechanisms for ESG performance, including Huazheng, Hexun, and Bloomberg; factors influencing ESG performance, such as government subsidies (Chen et al., 2024) and value-added tax refunds (Yu et al., 2023) positively promoting ESG, while economic policy uncertainty inhibits ESG performance; and the economic consequences of ESG, where there is controversy over the impact of ESG ratings on corporate green innovation, as noted by Li and Li (2023), Most studies indicate that corporate ESG performance promotes green transformation, but some scholars question the distinction between formalism and substantivism, arguing that while the quantity of green innovation increases, its quality decreases, exacerbating the green innovation bubble (Liu et al., 2023; Meng et al., 2023). The impact of ESG on corporate green innovation capabilities and related mechanism analyses remain under-researched. Exploring the impact of ESG ratings on corporate green innovation capabilities not only helps companies optimize their strategic decision-making and achieve sustainable development goals but also provides scientific basis for government policy formulation and rational investment decisions. Therefore, this paper continues to employ a multi-period difference-in-differences model to study the impact of ESG ratings on corporate green innovation capabilities.

The potential contributions of this paper. By deepening research on localization mechanisms, this paper focuses on the Chinese context and thoroughly explores the unique mechanisms through which ESG ratings influence corporate green innovation under China's distinctive institutional framework, addressing the gap in existing research that often relies on international frameworks and lacks sufficient exploration of China's localized mechanisms. By identifying key moderating mechanisms, this paper not only validates the main effect of ESG ratings on green innovation but more importantly identifies and empirically tests the roles of two key moderating variables: financing constraints and supply chain influence. It reveals that financing constraints and supply chain influence are important boundary conditions affecting the conversion of ESG effectiveness, deepening our understanding of the complexity of ESG mechanisms. Combining heterogeneity analysis of corporate characteristics, this paper finds through an analysis of corporate scale heterogeneity that the promotional effect of ESG is more significant in larger companies and further explores the underlying resource acquisition capability differences. This provides a more detailed perspective on how companies with different characteristics respond to ESG ratings. Addressing concerns about “formalism,” this paper distinguishes between the quality and quantity of green innovation and finds that ESG ratings have a stronger promotional effect on high-quality innovation. This result provides partial empirical support for alleviating concerns that ESG ratings may lead to “formalistic innovation” or “innovation bubbles,” indicating that ESG ratings in the Chinese context are more likely to promote substantive innovation.

2. Literature Review and Theoretical Assumptions

2.1 Literature Review

ESG ratings, as an informal environmental regulatory tool, exert influence on corporate behavior through market mechanisms and have become an important lever for promoting sustainable development. At its core, ESG integrates environmental (E), social (S), and governance (G) responsibilities to provide companies with a standardized assessment framework, thereby guiding resources toward green innovation sectors. In the Chinese context, the importance of ESG ratings has become increasingly evident as policies have been

strengthened—the mandatory disclosure requirements under the 2023 "Measures for the Administration of the Disclosure of Enterprise Environmental Information" and the introduction of the Ministry of Finance's climate disclosure standards in 2025 have collectively enhanced the credibility of ratings. Ratings not only serve corporate compliance needs but also act as a strategic pillar for long-term competitiveness by reducing financing costs and alleviating information asymmetry. Existing research generally agrees that ESG ratings provide investors with reliable evidence of corporate environmental responsibility through a signaling effect, thereby optimizing capital allocation (Sun et al., 2025).

In terms of measuring and identifying the factors influencing a company's green innovation capabilities, existing research primarily uses the number of green patents—particularly combinations of invention patents and utility model patents—as core indicators. For example, Wang et al. (2025) used the number of green patent applications filed by heavily polluting enterprises to measure green innovation levels; Huang and Chen (2024) further divided green innovation capabilities into substantive innovation and strategic innovation, each measured using logarithmic indicators. Regarding influencing factors, existing studies have focused on dimensions such as policy, enterprise characteristics, and the integration of internal and external capabilities. Specifically, in terms of policy, Yang and Wang (2025) explored the promotional effect of green credit policies on substantive green innovation, while Zeng and Xiao (2023) studied the role of the Yangtze River Economic Belt development strategy in enhancing regional green innovation capabilities. In terms of firm characteristics, Mao and Wei (2023) examined the impact of state-owned capital participation on the green innovation capabilities of private enterprises, while Wan and Yang (2022) investigated the relationship between cross-border mergers and acquisitions and green innovation capabilities. From the perspective of internal and external factors, Zhao et al. (2023) examined the relationship between state-owned equity participation, absorption capacity, and green technological innovation in private enterprises, while Wu et al. (2024) investigated the impact of digital capabilities on green innovation in manufacturing enterprises. Xing and Xu (2024) explored the relationship between digital transformation, dynamic capabilities, and green innovation in manufacturing enterprises. Most studies confirm the positive promotional effect of ESG performance on green innovation (Lu et al., 2024), but Liu et al. (2023) raise concerns about "formalism," arguing that under soft regulation of ESG ratings, companies may only symbolically increase the quantity of green innovation, such as utility patents, while the quality of substantive innovation, such as invention patents, may decline, creating an "innovation bubble." Li and Chen (2024) further validated that ESG rating uncertainty leads to an increase in the quantity of green innovation but a decrease in its quality. Market pressure drives companies to pursue short-term visible results, while financing constraints inhibit investments in high-quality innovation.

Although existing research has yielded abundant results, there remain key gaps in understanding the impact of ESG performance on green innovation: first, insufficient exploration of localization mechanisms. Most existing studies draw on international frameworks, with limited analysis of the interactive mechanisms between China's "dual carbon" goals, state-owned enterprise reforms, and other distinctive institutional arrangements and ESG. For example, while some studies mention the intermediary role of tax incentives (Li et al., 2023), they do not delve into the synergistic effects between green financial policies and ESG. Second, there is a lack of research on dynamic effects and long-term impacts. Most studies are based on cross-sectional or short-panel data, lacking tracking of the long-term relationship between changes in ESG ratings and green innovation. Hu et al. (2023) validated the short-term promotion of green transformation by ESG ratings but did not explore the lag effects of innovation outcomes converting into market competitiveness. Third, there is insufficient in-depth exploration of industry and property rights heterogeneity. While existing studies have mentioned differences between state-owned and private enterprises, as well as between high-pollution and non-polluting industries (Zhao & Li, 2024), they have not deeply analyzed the impact of industry-specific technical characteristics—such as high-tech versus traditional manufacturing—on the transmission pathways of ESG. Fourth, the moderating role of ESG disclosure quality has been overlooked. While academia has examined the factors influencing ESG disclosure and its economic consequences (Song et al., 2025), the regulatory mechanisms of disclosure quality—such as authenticity and comparability—on green innovation remain unclear. Whether high-quality disclosure can mitigate the "innovation bubble" (Liu et al., 2023) or enhance the financing constraint mitigation effect (Zhang et al., 2024) requires empirical testing.

2.2 Theoretical Assumptions

Based on the aforementioned theoretical framework and research gaps, this paper attempts to explore the intrinsic mechanisms through which ESG ratings influence green innovation, while taking into account the unique characteristics of the Chinese context. The driving force of ESG ratings on green innovation can be achieved through three mechanisms: first, mitigating information asymmetry. The independent assessments conducted by third-party rating agencies provide the market with reliable signals regarding a company's environmental performance, thereby reducing investors' risk perceptions and improving the company's access to financing channels and cost structure (Sun et al., 2025); Second, it reinforces the reputation supervision effect. The enhanced transparency of ESG information disclosure creates a market-driven mechanism, prompting companies to internalize environmental responsibility as a core competitive advantage, suppressing short-term "greenwashing" behavior, and driving substantive technological breakthroughs—the mandatory disclosure requirements under the 2023 "Administrative Measures for the Legal Disclosure of Corporate Environmental Information" further enhance the effectiveness of this mechanism (Li et al., 2023; Liu et al., 2023); Third, optimize resource allocation guidance. The ESG framework guides companies to reassess the negative externalities of high-pollution production capacity and accelerate the transfer of traditional production factors to green R&D areas. Under China's unique policy coordination, the rigid constraints of legally mandated environmental information disclosure and market incentives for environmental responsibility further amplify the effects of the aforementioned mechanisms.

However, the promotional role of ESG in green innovation may be constrained by two key factors: first, financing constraints. Financing constraints constitute a key resource barrier to the transformation of ESG into green innovation. When companies face credit rationing or high financing costs, the financing advantages leveraged by ESG ratings are difficult to effectively convert into R&D investments, especially under China's multi-tiered capital market structure: the credit preferences of state-owned banks have led to long-term financing discrimination against small and medium-sized enterprises, resulting in severe financing constraints and a low promotional effect of ESG on companies' green innovation levels; second, supply chain influence. A company's control over the supply chain serves as the leverage point for ESG-driven innovation. Companies with high influence, such as supply chain leaders, can amplify ESG effects through two pathways: vertically, by leveraging procurement bargaining power to embed ESG standards into supplier selection systems, thereby compelling upstream raw material suppliers to adopt green practices to ensure the compliance of end-product technology implementation (Shi & Yan, 2024); and through horizontal value-added initiatives, they can use green certifications to create product differentiation advantages, converting ESG investments into market premiums to offset innovation costs (Wu et al., 2024). China's "pyramid-shaped" industrial chain structure creates a unique context for this mechanism—ESG demands from downstream leading companies are transmitted through orders to create strong incentives, such as new energy vehicle manufacturers' carbon footprint requirements for battery suppliers. However, the efficiency of upstream transmission highly depends on the control power of core enterprises (Zhen & Sun, 2025). This asymmetric structure makes bargaining power a key variable in ESG resource integration.

Based on the above analysis, this paper proposes the following research hypotheses:

H1: ESG ratings significantly enhance corporate green innovation capability;

H2: Financing constraints weaken the positive effect of ESG on green innovation;

H3: Supply Chain discourse strengthens the positive effect of ESG on green innovation.

3. Research Design

3.1 Sample Selection and Data Sources

This paper takes Chinese A-share listed companies from 2009 to 2023 as the research object and selects corresponding enterprise, industry, and provincial-level data for empirical testing. The ESG rating data involved in this paper mainly comes from SynTao Green Finance ESG Rating Data Platform, while the green patent data of enterprises comes from the Chinese Research Data Services (CNRDS). Other enterprise and industry-level data comes from the CSMAR database. The following processing was performed on the data obtained: (1) Financial and real estate sectors were excluded; (2) ST, *ST, or PT stocks were excluded, along

with companies listed for less than one year, those that have been delisted, or those suspended from listing, to reduce the impact of corporate operational risks; (3) Missing samples were excluded; (4) To reduce the impact of outliers, all continuous variables were subject to 1% trimmed tail processing. After processing, 41,792 data points from 4,903 stocks were obtained, distributed across all industries except the financial and real estate sectors, and geographically distributed across the 31 provincial-level administrative regions of mainland China and the Hong Kong Special Administrative Region.

3.2 Model Construction and Variable Selection

The Staggered DID model is a commonly used policy evaluation method to assess the impact of policy implementation on corporate behaviour. The model identifies the net effect of a policy by comparing the differences before and after the policy implementation, and between firms affected by the policy and those not affected by the policy. In the study of the impact of ESG ratings on firms' green innovation, the Staggered DID model can effectively assess the impact of ESG ratings issuance on firms' green innovation behaviours and mitigate endogeneity problems.

Since the government departments have not formulated formal ESG rating standards, the existing ESG data are mainly released by third-party rating agencies, which are subject to the supervision of the market and relevant enterprises; this paper refers to Hu et al. (2023) to regard it as a governance mechanism from the external market, and constructs a Staggered DID model to verify Hypothesis H1, i.e., the impact of ESG ratings on the green technological innovation capability of enterprises. In this paper, based on the exogenous shock of ESG ratings of listed companies announced for the first time by SynTao Green Finance, the model is constructed as follows:

$$Greeninnovation_{it}=\alpha+\beta ESG1+\gamma X_{it}+\mu_i+\lambda_t+\varepsilon_{it} \quad (1)$$

Where i is the firm, t is the year, and the explanatory variable $Greeninnovation_{it}$ is the green innovation capability of firm i in year t. In this paper, we refer to Wang and Wang (2021) and Li and Zheng (2016) to measure the green innovation capability of firms by the number of their green patent applications. Specifically, this paper sums up the number of green invention patent applications and the number of green utility model patent applications, and takes the natural logarithm after adding 1 to get the total green innovation Greennum, which is used to represent the green innovation capability of the enterprise; at the same time, the number of green invention patent applications therein is used as an indicator of the quality level of green innovation, and takes the natural logarithm after adding 1 to get Greennum2; the number of green utility model At the same time, the number of green invention patent applications is taken as an indicator of the quality level of green innovation, and the natural logarithm is taken after adding 1 to get Greennum3.

ESG1 is the core explanatory variable, which takes 1 in year t and thereafter and 0 before year t for enterprise i if the ESG rating data of enterprise i in year t is first published by SynTao Green Finance, and 0 if no ESG rating data is published in the observation period.X_{it} is a series of control variables, which refer to the practices of Xu and Cui (2020) and Zhao and Zhang (2020), and specifically include: enterprise size Insize, enterprise age Age, property right nature Pro, two-job Dual, independent director proportion Indep, director size Board, gearing ratio Lev, the proportion of shares held by the first largest shareholder Top1, return on assets Roa, enterprise value TobinQ, GDP per capita at the city level lnpgdp, and industrial structure Industry, the specific The definitions of the variables are shown in Table 1. μ_i is the individual fixed effect, λ_t is the time fixed effect, and ε_{it} is the random error term. β is the focus of this paper, and if β is significantly positive, it means that ESG ratings of enterprises have a significant positive effect on the green innovation capability of enterprises, and vice versa has a negative effect.

4. Empirical Results and Analyses

4.1 Descriptive Statistics

The descriptive statistics of each variable are shown in Table 2. From the results, it can be seen that the mean value of the total number of green patent applications (plus 1 to take the logarithm) of listed companies during the study period is 0.4232, and the standard deviation is 0.8379, with the minimum value of 0 and the maximum value of 3.8501, which reflects that the overall level of green innovation of listed companies is weak,

and that there is a large gap in the green innovation ability between different companies.The mean value of ESG1 is 0.1373 and the standard deviation is 0.3442, indicating that enterprises that have published ESG ratings during the sample period account for 13.73% of the total sample. Among the control variables, the mean value of firm size is 22.1376, the maximum value is 26.1096, and the minimum value is 19.7365, which indicates that the sample contains firms of different sizes, and the mean value of firms' total gearing ratio is 41.59 per cent, and the yield is 4.03 per cent, which is within a reasonable range. Meanwhile, the mean value of variance inflation factor is 1.52, which is much lower than the critical value of 10, and it can be seen that there is no obvious multicollinearity among variables.

Table 1: Definition of variables

Variable type	Variable name	Variable symbol	Variable Definition
Explanatory variable	SynTao Green Finance ESG	ESG1	Firm i's ESG rating data for year t is taken as 1 in year t and thereafter, and 0 prior to year t if SynTao Green Finance first publishes ESG rating data for firm i. If no ESG rating data is published in the observation period, it is taken as 0
Explained Variables	Number of firms' green innovations	Greennum	Green patent applications , sum of green invention patents and utility model patents + 1 to take logarithmic values.
	Quality level of green innovation	Greennum2	Green invention patents+1take the logarithm
	Green Innovation Quantity Level	Greennum3	Patents for Utility Models +1 taking logarithms
Control Variables	Insize	Insize	Natural logarithm of total assets at the end of the year
	Age	Age	Ln(1+time of establishment of the enterprise)
	Nature of ownership	Pro	1 for state-owned enterprises, 0 for non-state-owned enterprises
	Gearing ratio	Lev	Total liabilities/total assets
	Return on assets	Roa	Net Profit/Total Assets
	Shareholding Ratio of Top Shareholders	Top1	Shareholding of Top 1 Shareholder/Total Share Capital
	Enterprise Value	TobinQ	Market value of enterprise/replacement cost of capital Taking natural logarithm
	Dual	Dual	Whether the chairman and general manager are the same person. Yes=1; No=0
	Proportion of independent directors	Indep	Number of independent directors/total number of board members
	Board Size	Board	Ln(1+number of directors)
	GDP per capita	lnpgdp	Logarithmic value of GDP per capita at city level
	Industry Structure	Industry	Share of secondary industry in GDP at city level

Table 2: Descriptive statistics of main variables

Variable	Obs	Mean	Std. dev.	Min	Max
ESG1	41,792	0.1373	0.3442	0.0000	1.0000
Greennum	41,792	0.4232	0.8379	0.0000	3.8501
Greennum2	41,792	0.2954	0.6802	0.0000	3.4340
Greennum3	41,792	0.2410	0.5876	0.0000	2.8904
Insize	41,792	22.1376	1.2732	19.7365	26.1096
Age	41,792	2.9232	0.3383	1.9459	3.5835
Pro	41,792	0.3377	0.4729	0.0000	1.0000
Dual	41,792	0.2957	0.4563	0.0000	1.0000
Indep	41,792	0.3758	0.0529	0.3333	0.5714
Board	41,792	2.2338	0.1755	1.7918	2.7081
Lev	41,792	0.4159	0.2095	0.0512	0.9490
Top1	41,792	0.2984	0.1784	0.0000	0.7298
Roa	41,792	0.0403	0.0686	-0.2476	0.2593
TobinQ	41,792	0.5814	0.4773	-0.1643	2.1692
lnpgdp	41,792	11.2454	0.5064	9.9144	12.1565
Industry	41,792	0.4063	0.0934	0.1580	0.5557

4.2 Benchmark Regression Results

Table 3 illustrates the results of the baseline regression of the impact of SynTao Green Finance ESG ratings on firms' green innovation capacity, using individual and time fixed effects.

As shown in columns (1) and (2) of Table 3, the regression coefficient of ESG1 is significantly positive at the 1% level, and remains significant even after controlling for firm-level variables. The regression coefficient of ESG1 for the total volume of green innovation is 0.1219, indicating that obtaining an ESG rating can increase a firm's total volume of green innovation by 12.19%, thereby validating the positive role of ESG ratings in enhancing a firm's green innovation capabilities. As shown in columns (3) and (4), the regression coefficient of ESG1 for the quality of corporate green innovation is 0.1129, indicating that obtaining an ESG rating can increase the quality of corporate green innovation by 11.29%. As shown in columns (5) and (6), the regression coefficient for ESG1 on the quantity of green innovation is 0.0568, indicating that obtaining an ESG rating can increase the quantity of green innovation by 5.68%. This suggests that ESG ratings significantly promote green innovation and validates hypothesis H1. Furthermore, the comparison between columns (4) and (6) indicates that the promotional effect of ESG ratings on green invention patents is slightly greater than that on green utility model patents.

Table 3: Benchmark regression results

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Greennum No	Greennum Yes	Greennum2 No	Greennum2 Yes	Greennum3 No	Greennum3 Yes
ESG1	0.1414***	0.1219***	0.1287***	0.1129***	0.0674***	0.0568***
	(6.5711)	(5.5935)	(6.9940)	(6.0177)	(4.0783)	(3.3831)
Controls	No	Yes	No	Yes	No	Yes
Constant	0.2303***	-1.5347**	0.1333***	-1.6988***	0.1466***	-0.5152
	(16.1518)	(-2.5687)	(11.0182)	(-3.6503)	(14.2815)	(-1.1109)
Observations	41,792	41,792	41,792	41,792	41,792	41,792
R-squared	0.037	0.040	0.032	0.036	0.023	0.025
Number of Stkcd	4,903	4,903	4,903	4,903	4,903	4,903

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

4.3 Robustness Tests

4.3.1 Parallel Trend Test and Dynamic Effects Analysis

This paper employs an event study method to test whether the sample adheres to the trend of maintaining consistency between the experimental group and the control group prior to the policy implementation time point, i.e., whether it passes the parallel trend test. Additionally, it examines the dynamic effects of ESG ratings on corporate green innovation capabilities. Since corporate ESG ratings are disclosed at different time points based on their own circumstances, the policy time virtual variable cannot be set to a single year. This study sets the year when a company first discloses its ESG rating as the time dummy variable Current. Based on each company's specific circumstances, Pre_* and las_* are set, resulting in parallel trend test plots for Greennum, Greennum2, and Greennum3. As shown in Figure 1, the relative time dummy variables before the implementation of ESG ratings are mostly insignificant, indicating that there are no significant differences between the treatment group and the control group during the period before the publication of ESG ratings. However, the relative time dummy variables after the publication of ESG ratings are mostly significant, indicating that there are significant differences between the treatment group and the control group after the publication of ESG ratings, thus passing the parallel trend test required by the difference-in-differences model. As the effect gradually increases after the publication of ESG ratings and then slightly decreases, this dynamic effect may stem from: during the early stages of ESG ratings, companies have a high level of attention on green innovation and make significant R&D investments, leading to gradually noticeable effects; however, as time progresses, companies' attention on green innovation slightly decreases or they encounter difficulties in the R&D process, resulting in a slight decline in the effect, with a certain degree of diminishing marginal effects. Figure 2 indicates that the promotional effect of ESG ratings on green invention patents is more significant than on green utility model patents compared to Figure 3.

Figure 1: Parallel trend test of Greennum

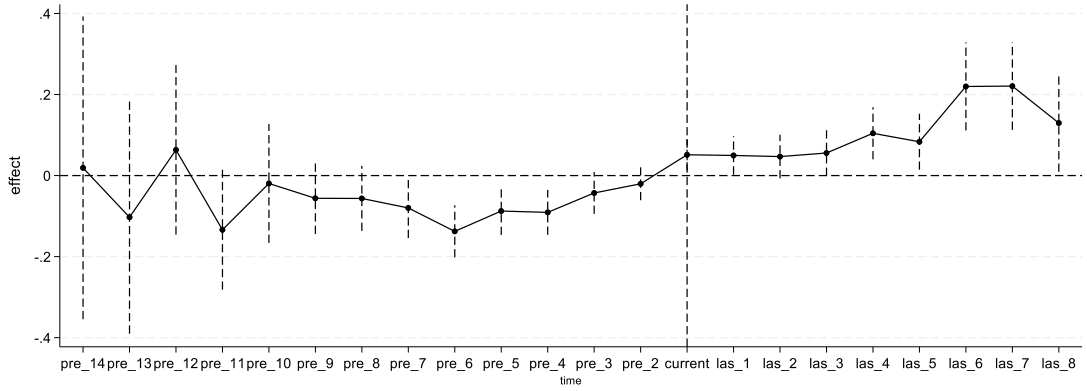


Figure 2: Parallel trend test of Greennum2

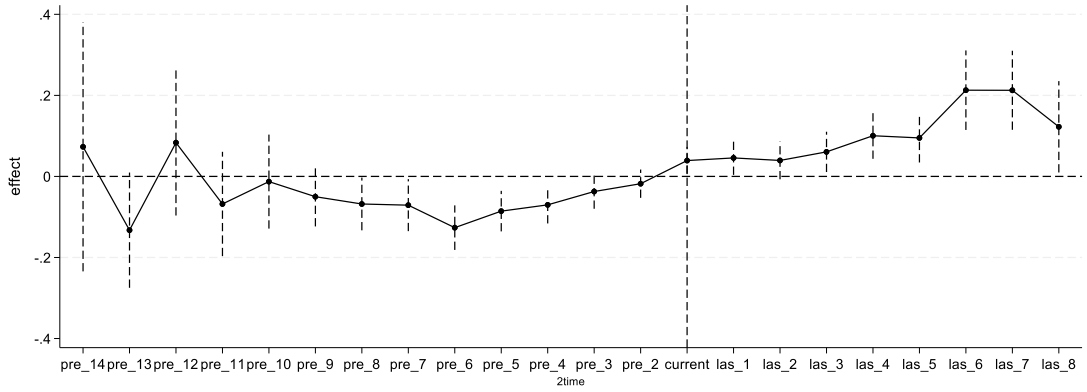
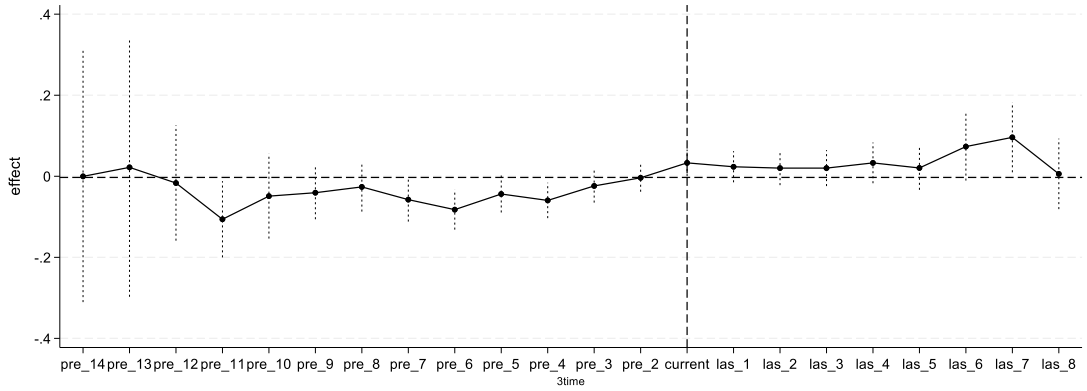


Figure 3: Parallel trend test of Greennum3



4.3.2 Placebo Test

This paper controls for the effects of multiple indicators outside of ESG ratings on the treatment and control groups using benchmark regression. However, there are still some potential factors at the firm and year levels that may influence the results. This paper references Tang et al. (2022) to conduct a Staggered DID mixed-fiction placebo test. Specifically, this paper randomly selects 984 new samples from all samples, the same number as the original treatment group, and simultaneously generates pseudo-treatment groups and pseudo-ESG disclosure times. By randomly assigning ESG-rated companies and disclosure years, 500 random samples are conducted. Figure 4 shows that the true estimated result of ESG1 for Greennum is $\beta = 0.1219$, far from the spurious regression coefficient. The randomized estimated coefficients are distributed on both sides of 0, with the vast majority of P-values > 0.1, indicating that after mixed counterfactuals, the implementation effect is significantly reduced in both significance and strength. Figures 5 and 6 show that Greennum2 and Greennum3 also passed the placebo test, confirming the robustness of the conclusion.

Figure 4: Placebo test for Greennum

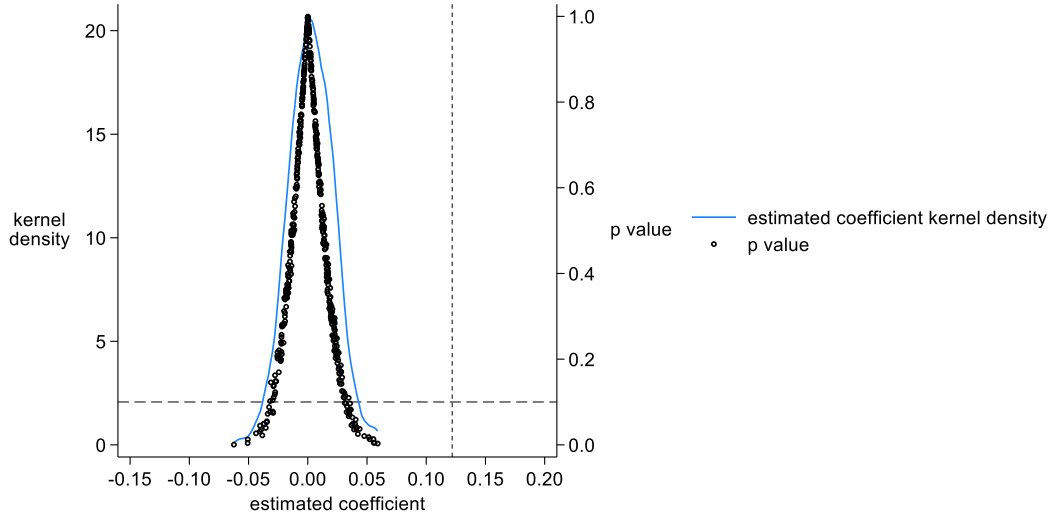


Figure 5: Placebo test for Greennum2

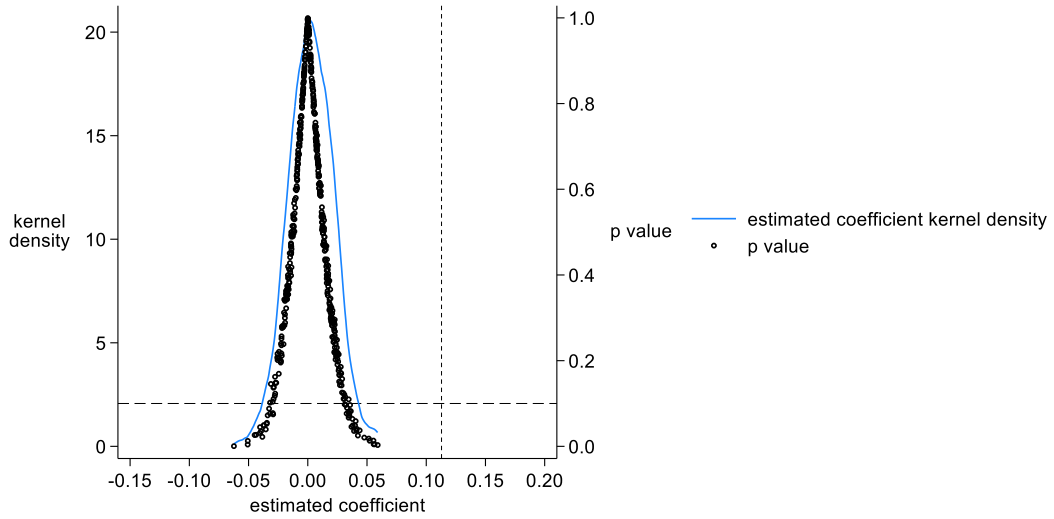
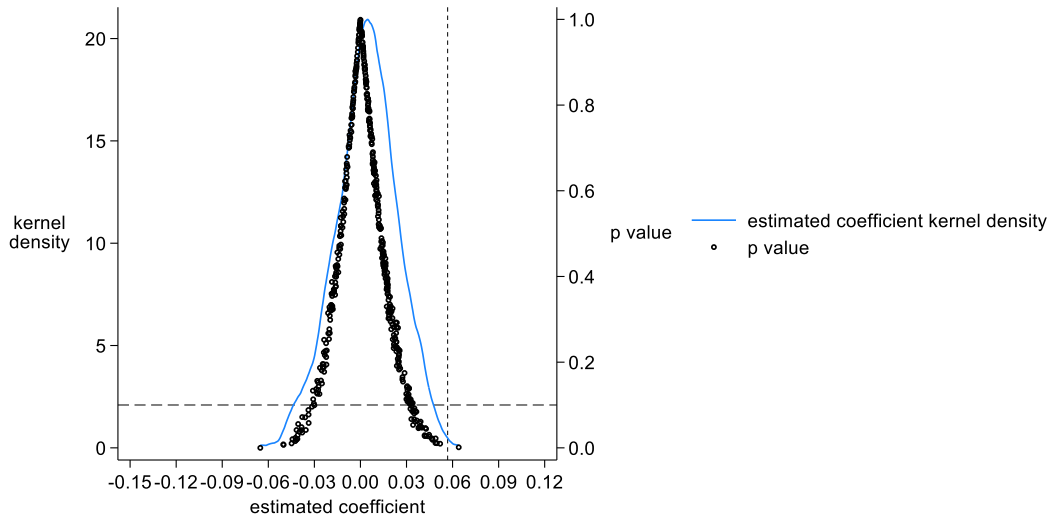


Figure 6: Placebo test for Greennum3



4.3.3 Changing the Sample Interval

The COVID-19 pandemic began in December 2019. In January 2020, the World Health Organization declared the pandemic a Public Health Emergency of International Concern (PHEIC), which had a significant impact on the global economy, leading to disruptions in global supply chains, business closures, and sharp declines in consumption and investment. The pandemic continued to affect the global economy in 2021 and 2022. In 2023, the world entered the post-pandemic era. To minimize the disruption caused by the COVID-19 pandemic on corporate green innovation, this study excludes samples from 2020 to 2022 and examines the impact of ESG ratings on corporate green innovation. The regression results in Table 4 show that the regression coefficients for Greennum, Greennum2, and Greennum3 are 0.1228, 1.1171, and 0.0567, respectively, which are statistically significant at the 1% level and robust.

Table 4: Regression results for changing sample intervals

	(1)	(2)	(3)
VARIABLES	Greennum	Greennum2	Greennum3
ESG1	0.1228***	0.1171***	0.0567***
	(5.4569)	(5.9460)	(3.3233)
Controls	Yes	Yes	Yes
Constant	-1.2719**	-1.6371***	-0.3238
	(-2.0829)	(-3.3681)	(-0.6995)
Observations	29,625	29,625	29,625
R-squared	0.032	0.033	0.017
Number of Stkcd	4,900	4,900	4,900

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

Although this paper has validated the robustness of its core conclusions through parallel trend tests, placebo tests, and sample interval adjustments, caution should still be exercised regarding the potential limitations of the methodology and empirical design. While the Staggered DID model leverages the exogenous shock from the publication of SynTao Green Finance ESG ratings to mitigate endogeneity issues, unobserved confounding factors may still influence both rating acquisition and innovation behavior through non-random pathways, thereby compromising the purity of causal inference. This study provides empirical support for ESG-driven green innovation within the existing methodological framework. However, the aforementioned limitations suggest that future research should explore deeper mechanisms through mixed methods such as corporate case tracking, multi-source rating cross-validation, and granular supply chain data.

5. Heterogeneity Analysis

5.1 Heterogeneity Analysis of Enterprise Size

From a resource perspective, larger enterprises are better positioned to meet the financial reserves and technological accumulation required for green innovation. ESG investments require long-term capital support, and large enterprises face lower financing constraints due to lower bond issuance costs and broader credit channels. Additionally, economies of scale confer advantages in R&D efficiency. Therefore, this study categorizes enterprises into large and small/medium-sized enterprises based on median enterprise size and conducts grouped regression analysis. Table 5 columns (1) and (2) report the grouped regression results for the impact of ESG on the green innovation capabilities of large-scale enterprises and small/medium-sized enterprises. For large enterprises, the regression coefficient for ESG ratings is 0.0760, which is significant at the 1% level. For SMEs, the coefficient is -0.034 and not significant. This indicates that the promotional effect of ESG performance on green innovation capabilities is more pronounced in larger enterprises. A Fisher's exact test based on bootstrap sampling was conducted with 500 repetitions. The p-values from the intergroup coefficient difference test show that there is a significant difference between ESG performance and enterprise size.

Table 5: Results of firm size heterogeneity analysis

	(1)	(2)
VARIABLES	Large size	MedianSmall size
ESG1	0.0760***	-0.0340
	(3.1031)	(-0.8888)
Inter-group coefficient difference P value	0.036	
Controls	Yes	Yes
Constant	-3.4220***	-2.1684***
	(-3.0127)	(-3.9088)
Observations	20,896	20,896
R-squared	0.059	0.019

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

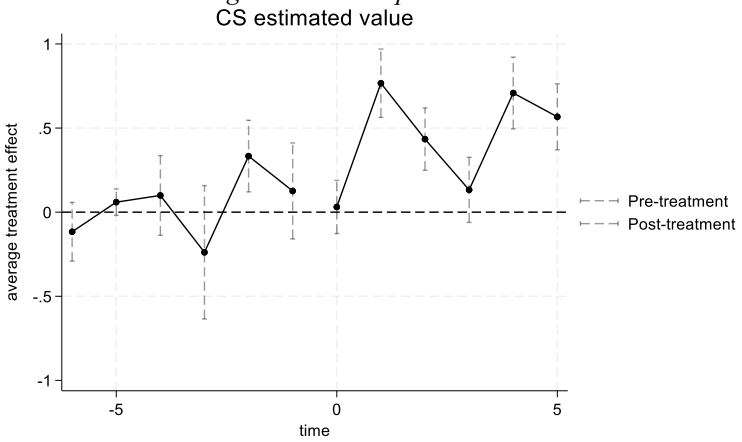
5.2 Heterogeneous Treatment Effects in CSDID

Since this paper may be affected by heterogeneous treatment effects, we refer to the CSDID proposed by Callaway and Sant'Anna (2021) to test the robustness of the multi-point estimates, which can be used to calculate the four different average treatment effects (ATT) shown in the table. The columns (1) and (3) of Table 6, and (4) of Table 6 have regression coefficients of 0.2535, 0.4871, and 0.1688, respectively, and are significant at the 1% level. The pre-treatment coefficient in column (2) is not significant, while the post-treatment coefficient is 0.4399, which is significantly positive at the 1% level. Figure 7 shows the results of the parallel trends test, demonstrating that the estimation bias caused by heterogeneous treatment effects does not result in severe impacts, and the conclusions are robust.

Table 6: CSDID regression results

	Simple ATT	Dynamic ATT	Calendar Time ATT	Group ATT
VARIABLES	(1)	(2)	(3)	(4)
Simple ATT	0.2535*** (0.0658)			
Pre_avg		0.0439 (0.0372)		
Post_avg		0.4399*** (0.0772)		
CAverage			0.4871*** (0.1017)	
CAverage				0.1688*** (0.0462)

Figure 7: CSDID parallel trend test



6. Further Analyses

Heterogeneity analyses reveal that ESG ratings have a significantly stronger effect on promoting green innovation in large firms than in SMEs. This difference implies that firm size per se is not the fundamental

driver, but rather the differences in resource acquisition capabilities behind it are the key moderating mechanism. Specifically, on the one hand, SMEs face higher financing costs, which may weaken the green investment capacity brought by ESG ratings; on the other hand, referring to Mao and Wei (2023), SMEs usually face higher supplier concentration, and the lack of voice restricts their ability to integrate industrial chain resources through ESG.

To verify the above hypotheses, this chapter constructs a moderating effect model to test how two types of resource barriers-financing constraints and supply chain discourse-affect the transmission efficiency of ESG to green innovation, thereby revealing the underlying mechanisms of the heterogeneity phenomenon.

6.1 Financing Constraints

The FC index is used to indicate the degree of a company's financing constraints, which is positively correlated with the severity of financing constraints. The results in column (1) of Table 7 show that after adding the moderating variable FCindex, the coefficient of the independent variable ESG1 is 0.1979, which is significant at the 1% level. The interaction term coefficient between ESG1 and FCindex is -0.3787, which is significantly negatively correlated at the 1% level. This indicates that the FC index weakens the positive relationship between ESG ratings and corporate green innovation capabilities, exerting a negative moderating effect. When the FCindex increases by 1 unit, the promotional effect of ESG on green innovation decreases by 37.87%. A higher FCindex indicates more severe financing constraints for the firm, thereby inhibiting the promotional effect of ESG on green innovation, supporting H2.

6.2 Corporate Supply Chain Influence

The supplier concentration PurchaseHHI is used to indicate a company's supply chain influence. It is calculated as the sum of the squares of the ratios of the procurement amounts from the top five suppliers to the total procurement amount. This is an inverse indicator, meaning that a higher value indicates lower supply chain influence. As shown in Column (2) of Table 7, after incorporating the moderating variable PurchaseHHI, the coefficient of the independent variable Purchase is 0.1371, which is significant at the 1% level. The interaction coefficient between ESG1 and PurchaseHHI is -0.0055, which is significantly negatively correlated at the 1% level. This indicates that the supplier concentration Herfindahl Index weakens the positive relationship between ESG ratings and a company's green innovation capabilities, exerting a negative moderating effect. A 1-unit increase in supplier concentration (PurchaseHHI) reduces bargaining power, weakening the ESG effect by 0.55%, reflecting the critical role of a company's control over its supply chain. When supply chain bargaining power is greater, it enhances the positive effect of ESG on a company's innovation capacity, supporting the validity of H3.

Table 7: Results of moderating effect

	(1)	(2)
VARIABLES	FCindex	PurchaseHHI
ESG1	0.1979***	0.1371***
	(5.2066)	(5.8921)
c.ESG1#c.FCindex_w	-0.3787***	
	(-3.7954)	
FCindex_w	0.1371***	
	(3.0170)	
c.ESG1#c.PurchaseHHI_w		-0.0055***
		(-2.9652)
PurchaseHHI_w		-0.0008
		(-1.3753)
Controls	Yes	Yes
Constant	-2.3724**	-1.5164**
	(-2.3783)	(-2.5407)
Observations	30,237	41,793
R-squared	0.049	0.041
Number of Stkcd	3,965	4,903

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

6.3 Conclusions and Implications

This study empirically examines the impact mechanism of ESG ratings on corporate green innovation capability based on a Staggered DID model. The core conclusion shows that ESG ratings have a significant promotion effect on corporate green innovation capacity, which drives the total green innovation of enterprises to increase by 12.19% through alleviating information asymmetry, strengthening reputational monitoring and optimising the resource allocation path. It is worth noting that the promotion effect of ESG on green invention patents is significantly higher than that of utility model patents, confirming that ESG ratings are more inclined to promote substantive innovation. Heterogeneity analysis reveals that the effect is particularly significant in larger enterprises, while SMEs do not show a significant positive response due to resource constraints. Mechanism tests further verify that: financing constraints and supply chain voice are the core regulating variables, for every unit increase in financing constraints index, the innovation promotion effect of ESG decreases by 37.87%; for every unit increase in supplier concentration, the ESG effect decreases by 0.55%, i.e., the financing constraints weaken the positive effect of ESG on green innovation, and the strengthening supply chain influence enhances the positive impact of ESG on green innovation, highlighting the key role of resource barriers and supply chain control.

Based on the above conclusions, this paper proposes three key insights. First, companies should establish an ESG-driven innovation strategy framework. Large enterprises should leverage their scale advantages to internalize ESG ratings as a sustainable driving force for green technology R&D, focusing on securing high-quality green patents. Small and medium-sized enterprises (SMEs) should break through resource constraints by collaborating on green supply chains—such as adopting leading companies' ESG procurement standards—or exploring asset-light innovation models like technology licensing and joint R&D. Second, policy design should strengthen a multi-tiered support framework. Regulatory authorities should improve ESG disclosure quality oversight, such as third-party certification traceability mechanisms, to curb "formality-driven innovation." Concurrently, they should optimize targeted support through green financial tools, such as establishing specialized ESG transition loans for SMEs and expanding the coverage of carbon reduction support tools, to facilitate the "rating-funding-innovation" transmission chain. Third, market mechanisms should emphasize the synergistic efficiency of the industrial chain. Encourage "chain-leading" enterprises to embed ESG standards into procurement contracts to drive green upgrades in upstream sectors, while developing ESG premium compensation mechanisms to achieve market-based cost-sharing for innovation, thereby continuously enhancing corporate supply chain influence.

This study provides theoretical support for the construction of a Chinese-style ESG ecosystem. Future research could explore three areas in greater depth: first, combining the "dual carbon" goals with dynamic assessments of the long-term innovative effects of ESG policies; second, analyzing the differentiated pathways through which the E/S/G dimensions influence green innovation; and third, tracking the governance mechanisms of ESG disclosure quality on "innovation bubbles," thereby providing a basis for constructing a policy system that balances innovation quality and sustainable growth.

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Conflicts of Interest

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