

Kai ZHAO, PhD (corresponding author)

zhaokai@qdu.edu.cn

Qingdao University, Qingdao, China

Yu GAO, Master's Student

gaoyu@qdu.edu.cn

Qingdao University, Qingdao, China

Xiaohe CHEN, Student

115524294@link.cuhk.edu.hk

The Chinese University of Hong Kong, Hongkong, China

Can ESG Ratings Promote Enterprise Green Innovation Efficiency? An Empirical Study from Chinese Listed Enterprises

Abstract. *As core microeconomic entities in a market economy, enterprises play an indispensable role in driving the green development of the economy and society. Environmental, Social and Governance (ESG) ratings act as a critical nexus between enterprises and the capital market, which effectively improves the transparency and efficiency of enterprise governance. Taking the initial release of ESG ratings for Chinese listed enterprises by SynTao Green Finance as an exogenous shock, this study empirically examines the impact of ESG ratings on enterprise green innovation using a multi-period difference-in-differences model, based on a panel sample of Chinese A-share listed enterprises covering the period 2010 to 2021. The baseline results show that ESG ratings significantly improve the efficiency of enterprise green innovation. Mechanism analysis further reveals that this promotional effect operates through three core channels: raising executive green cognition, alleviating enterprise financing constraints, and increasing enterprise R&D investment. Heterogeneity analysis demonstrates that the positive effect of ESG ratings on enterprise green innovation efficiency is more pronounced for heavily polluting enterprises, labour-intensive enterprises, asset-intensive enterprises, enterprises with green investor holdings, enterprises located in western China, and enterprises in regions with a high degree of openness.*

Keywords: *ESG ratings, green innovation efficiency, differences-in-differences, Green Finance.*

JEL Classification: O55, O12.

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1. Introduction

Escalating ecological degradation and frequent natural disasters (Xiang et al., 2022) threaten human livelihoods, the global economy, and social development,

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making green sustainable development a global priority. As the world's largest developing economy, China faces acute environmental challenges – its 2020 Environmental Performance Index (Yale-Columbia release) ranked 120th out of 180 countries (Song & Chen, 2023). Abandoning the unsustainable “high-input, high-consumption, high-pollution” model, China has advocated for a “market-oriented green tech innovation system”, green development modes, and an “innovation-driven strategy” (Tian et al., 2023). Enterprises, as core economic actors, drive both resource consumption/pollution and green innovation. Yet, green innovation's high costs, long payback cycles, risks, and externalities reduce firms' investment motivation – making it critical to explore ways to boost corporate green innovation.

Before the ESG (Environment, Social, Governance) frameworks prevailed, China relied on “top-down” formal environmental regulations. While these pushed firms toward greener practices, they suffered from “government initiative, enterprise passivity, public inertia”, imprecise enforcement, and even higher costs that hurt competitiveness (Murty et al., 2003). Informal regulations emerged as a complement, and ESG – assessing firms' environmental, social, and governance performance – has since become a micro benchmark. Firms integrating ESG and seeking third-party ratings adopt greener practices, enhance social responsibility, and optimise governance, gaining motivation for green innovation. However, key questions remain: Do ESG ratings promote corporate green innovation? How? And what heterogeneous factors matter? Few studies have addressed these issues.

This study uses the initial ESG rating release for Chinese listed firms to explore ESG's impact on corporate green innovation, examining three mechanisms: easing financing constraints, raising executive green cognition, and increasing R&D investment. It also analyses heterogeneous effects from industry, green investors, location, regional openness, and factor intensity. Results show ESG ratings significantly improve green innovation efficiency via the three mechanisms; the effect is stronger for polluting firms, those with green investors, eastern-located firms, low-openness region firms, and labour/asset-intensive firms. This study makes three marginal contributions: First, it focuses on green innovation efficiency instead of just output quantity. Second, it frames ESG as an informal regulation tool, clarifying its impact through three pathways, and expanding related literature. Third, it analyses heterogeneity from micro and macro perspectives for a holistic view.

The structure of this paper is outlined as follows: Chapter 2 develops the research hypotheses by systematically reviewing the relevant extant literature. Chapter 3 details the research design, including the constructed econometric model, data sources, and measurement of the core and control variables. Chapter 4 presents the empirical analysis of the impact of the ESG ratings on enterprises' green innovation efficiency, along with multiple robustness tests to verify the reliability of baseline findings. Chapter 5 identifies and validates three core paths through which ESG ratings improve enterprises' green innovation efficiency. Chapter 6 explores the heterogeneous effects of ESG ratings on this efficiency in different scenarios.

Chapter 7 summarises the full research findings and makes targeted policy recommendations accordingly.

2. Research hypotheses

2.1 ESG ratings and enterprise green innovation efficiency

Rooted in modern enterprise theory, firms are conceptualised as a nexus of contracts among factor owners. However, uncertainty, information asymmetry, bounded rationality, and high transaction costs inherently render these contracts incomplete – giving rise to moral hazard and adverse selection, as noted by Demsetz (1964). Resolving these frictions requires expanded information collection and reduced information asymmetry, a gap addressed by ESG ratings. Guided by signaling theory, ESG ratings not only showcase a firm’s performance in environmental management, social responsibility, and governance, but also embody its strategic commitment to environmental sustainability and green development (Wang et al., 2025a). By enhancing multi-dimensional and multi-level information disclosure and transparency, these ratings effectively mitigate information asymmetry between firms and their stakeholders (Gao et al., 2025). ESG ratings first act as a market-based governance mechanism to align green innovation incentives. In capital markets, improved ESG disclosure boosts transparency, alleviates adverse selection, and optimises resource allocation; firms with higher ESG scores further attract sustainability-focused capital and deliver superior excess returns, creating win-win outcomes for market and societal interests. In credit markets, financial institutions increasingly integrate ESG criteria into decision-making, screening high-performing green firms and providing preferential green credit – easing financing constraints for green innovation (Yang et al., 2025). In product markets, consumer preference for green goods drives firms to adopt green technologies and expand green offerings (Wang & Xu, 2025). In labor markets, high-ESG firms prioritise employee welfare, stimulating employee creativity and efficiency (Zhou et al., 2025). Collectively, these market-driven mechanisms internalise green development incentives, compelling firms to pursue green innovation proactively. Second, ESG ratings function as a stakeholder oversight tool. By reducing information asymmetry, they lower stakeholder monitoring costs and enhance supervision motivation (Nagriwum et al., 2025). Critically, when a firm’s operations cause environmental harm or stakeholder losses, ESG ratings rapidly capture such issues – reflected in timely downgrades. Stakeholders respond swiftly to downgrades to protect their interests, forcing firms to rectify non-sustainable practices and invest in green innovation. Based on these observations, the following hypothesis is proposed:

H1: *The publication of ESG ratings can promote enterprise green innovation efficiency.*

2.2 Mechanism of ESG ratings on enterprise green innovation

ESG ratings drive corporate green innovation by elevating executives' environmental awareness—a critical antecedent of firms' green strategic choices. Externally, ESG ratings attract scrutiny from media, investors, and analysts (Tan et al., 2025), compelling stakeholders to urge executives to prioritise and deepen their understanding of green practices to safeguard the firm's social reputation. Internally, executive cognition and information set directly shape organisational strategy (Hamrouni et al., 2019), with executive backgrounds, traits, experiences, and values being pivotal to organisational behavior and economic outcomes (Tan & Zhu, 2022; Wang et al., 2025b). For example, state-owned enterprise executives, who balance profit with non-commercial goals, are particularly responsive to such stakeholder pressures. Notably, the degree to which firms leverage resources for green innovation is tightly linked to managerial environmental consciousness. Executives with a strong environmental orientation are more likely to adopt eco-friendly practices, accelerate green transformations, and improve the efficiency of green innovation processes (Wang & Chu, 2024). By intensifying stakeholder attention and aligning executive priorities with green objectives, ESG ratings enhance executives' environmental awareness, which in turn motivates firms to engage in green innovation. The following hypothesis is proposed:

H2: *ESG ratings promote enterprise green innovation efficiency by raising executive green cognition.*

ESG ratings facilitate corporate green innovation by mitigating financing constraints – a major barrier to green innovation due to its unique characteristics (Wang & Zhang, 2025). Green innovation requires substantial capital investment and relies heavily on external financing (Ai et al., 2024), yet it faces greater challenges than traditional innovation: longer R&D cycles, higher failure risks, and market failures stemming from environmental externalities (Huang et al., 2022). These attributes amplify financial constraints, making stable external financing a prerequisite for high-quality green innovation (Zhang et al., 2022) – especially for green invention and energy-saving patents, where financial limitations are the primary R&D bottleneck (Albort-Morant et al., 2018). ESG ratings address this by reducing information asymmetry between firms and capital providers. Enhanced transparency from ESG disclosures helps investors and financial institutions assess firms' green innovation commitment and investment risks (Huang et al., 2023). This translates to two key benefits: first, ESG-rated firms gain access to more external financing (Shen et al., 2025); second, they secure lower financing costs – investors, armed with non-financial ESG information, perceive reduced default and market risks, enabling firms to negotiate lower debt, equity, and equity financing costs (Apergis et al., 2022; Gigante & Manglaviti, 2022; Chen et al., 2023; Bai et al., 2022). Additionally, ESG-aligned practices attract socially responsible investors, further lowering external financing costs (Ghoul et al., 2017). The following hypothesis is proposed:

H3: *ESG ratings promote enterprise green innovation efficiency by alleviating financing constraints.*

ESG ratings drive green innovation by incentivising and compelling firms to increase R&D investment – an essential input for green technology innovation and application. Green R&D differs from traditional R&D in its higher capital requirements (Liu et al., 2025), longer cycles, and greater risks; it also exhibits strong positive externalities, as social benefits often outweigh private gains (Guerrero-Villegas et al., 2018). These traits reduce the firms' intrinsic motivation to invest in green R&D, leading to underinvestment relative to what is needed for impactful green innovation. ESG ratings counter this by dual mechanisms. First, market-driven incentives: ESG disclosures enhance transparency around firms' green R&D activities, allowing the market to better evaluate their potential value (Li et al., 2025). This partially internalises R&D externalities, motivating firms to boost R&D spending. Second, stakeholder oversight: Dynamic ESG ratings link high scores to strong social responsibility and reputation. To maintain high ratings, firms must reduce pollution and offer green products (Tang et al., 2024). The way to meet this demand is through increased R&D investment. With stable green R&D investment as a foundation (Bouchmel et al., 2024), firms are more likely to explore and implement eco-friendly technologies, achieving both sustainable development and economic benefits (Islam et al., 2025). The following hypothesis is proposed:

H4: *ESG ratings promote enterprise green innovation efficiency by increasing R&D investment.*

3. Research design

3.1 Model design

This paper derives from the quasi-natural experiment associated with SynTao Green Finance's inaugural disclosure of ESG ratings for Chinese listed enterprises, the following model is constructed by using a multi-temporal Differences-in-Differences model to identify the impact of ESG ratings on enterprises' green innovation:

$$GreenInnov_{it} = \lambda_0 + \lambda_1 ESG_{it} + \gamma X_{it} + u_i + \eta_t + \varepsilon_{it} \quad (1)$$

where i represents an individual firm, t represents time, and the explained variable $GreenInnov_{it}$ is the green innovation efficiency of enterprise i in year t , ESG_{it} is the explanatory variable. ESG_{it} is a dummy variable. If enterprise i receives a rating in year t , it will be classified as a treatment group, then $ESG_{it}=1$; otherwise, $ESG_{it}=0$. X_{it} is the set of all control variables in this paper, u_i is an individual-level fixed effect, η_t is a time-level fixed effect, ε_{it} is the random disturbance term. Robust standard errors are clustered at the enterprise level to account for potential serial correlation and heteroskedasticity.

The Differences-in-Differences model needs to satisfy the parallel trend test, and to verify that it does, the following model is used:

$$\begin{aligned}
 GreenInnov_{it} = & \lambda_0 + \beta_s^{precut} [D_i \times I(t - T_D < -5)] \\
 & + \sum_{s=-5}^{-1} \beta_s^{pre} [D_i \times I(t - T_D = s)] \\
 & + \sum_{s=1}^5 \beta_s^{post} [D_i \times I(t - T_D = s)] + \beta_s^{postcut} [D_i \times I(t - T_D > 5)] + \gamma X_{it} + u_i + \eta_t + \varepsilon_{it} \quad (2)
 \end{aligned}$$

where $D_i = 1$ indicates that enterprise i is in the treatment group and $D_i = 0$ indicates that enterprise i is in the control group; $I(\cdot)$ is the indicator function, which takes the value of 1 when the condition in parentheses is true, and 0 otherwise; T_D is the period in which the enterprise first obtains an ESG rating, and the relative time is defined as $s = t - T_D$, which is the number of periods between the current year of the sample and the year in which the enterprise first obtains an ESG rating. This paper uses the period when the enterprise first obtains an ESG rating ($s = 0$) as the base period, and the test window covers 5 years before the rating to 5 years after the rating ($s \in [-5, 5]$). The meanings of the other variables are consistent with those in Equation (1). The core coefficient β_s^{pre} is the dynamic effect before the ESG rating disclosure. If it is not significantly different from 0, it indicates that the treatment group and the control group meet the parallel trend hypothesis. β_s^{post} is the dynamic effect after the policy implementation. Its significance and coefficient size reflect the continuous impact of the ESG rating on the enterprise's green innovation.

This study delves into the pathways by which ESG ratings enhance green innovation within enterprises. To quantify the mediation effect, the Bootstrap method is employed, setting the number of iterations at 3000. Further analysis involves a heterogeneity grouping test among enterprises, categorising them based on pollution levels, engagement with green investors, geographical location, openness to international markets, and varying operational factors. The analysis utilises the subsequent model to examine these distinctions:

$$GreenInnov_{it} = \lambda_0^l + \lambda_1^l ESG_{it} + \gamma^l X_{it} + u_i^l + \eta_t^l + \varepsilon_{it}^l, M = 1 \quad (3)$$

$$GreenInnov_{it} = \lambda_0^h + \lambda_1^h ESG_{it} + \gamma^h X_{it} + u_i^h + \eta_t^h + \varepsilon_{it}^h, M = 0 \quad (4)$$

where M represents a grouping variable for various enterprise characteristics, including the degree of pollution, the presence of green investors, the geographical location, the openness to external influences, and types of factors. The other variables retain the same definitions as in Equation (1).

3.2 Sample selection and data sources

Our initial sample consists of A-share firms listed on the Shanghai Stock Exchange and Shenzhen Stock Exchange of China over the period from 2010 to 2021. We collect data from multiple mainstream and authoritative databases in China, with variable-specific sources detailed as follows: Data for explained variable, including green patent applications and R&D expenditure, is obtained from the Chinese

Research Data Services Platform (CNRDS). The ESG rating data from Huazheng Index and SynTao Green Finance is sourced from the Wind Database (WIND). Data for all other control variables is retrieved from the China Stock Market & Accounting Research Database (CSMAR). To ensure the reliability and integrity of the research data, we apply the following standard screening and cleaning procedures to the raw sample: First, we exclude financial and insurance firms, whose operating models and accounting standards are systematically different from non-financial firms. Second, we remove firms under Special Treatment (ST) or *ST (delisting risk warning), as these firms face financial distress and may produce abnormal operating and financial data. Third, we drop firm-year observations with missing values for core variables to avoid estimation bias. Fourth, we winsorise all continuous variables at the 5th and 95th percentiles to mitigate the potential impact of extreme outliers. After applying the above procedures, we obtain a final unbalanced panel dataset comprising 24,499 firm-year observations for our empirical analysis.

3.3 Variable selection

3.3.1 Core explanatory variable

As Chinese enterprises grow more focused on ESG information, a host of third-party rating agencies have launched ESG rating products. Among these, SynTao Green Finance stands out: it is China's earliest provider of ESG rating data and the first domestic service provider to sign the UN Principles for Responsible Investment. Its annual reports – Responsible Investment in China and ESG Rating Analysis of A-share Listed Enterprises – are highly regarded by the capital market for their authority. According to the ESG rating data published by SynTao Green Finance, if enterprise i receives a rating in year t , it will be classified as a treatment group, then $ESG_{it}=1$; otherwise, $ESG_{it}=0$. This article has fully verified the sample data. Within the full sample period of the SynTao Green ESG rating, there is no case where company i has corresponding ESG rating data in year t but no rating data in year $t+1$ and thereafter. That is, once a sample company is included in the disclosure scope of SynTao Green ESG rating (entering the treatment group), it will continue to be included in the rating system in subsequent years and will not be returned to the control group.

3.3.2 Explained variable

For enterprises' green innovation efficiency, existing literature often uses a comprehensive indicator system for measurement. Some relevant indicators can be sourced from enterprises' ESG or social responsibility reports, yet they overlap with this study's core explanatory variable (ESG rating) and risk-causing bias. To avoid this, this paper measures green innovation efficiency as the ratio of output to input. Since direct data on listed enterprises' green innovation inputs is hard to obtain,

annual R&D expenditure is used as a proxy. For the outputs, we quantify them with the natural logarithm of the total patent applications plus one.

3.3.3 Control variables

This study incorporates key financial and governance metrics to account for core factors affecting enterprises' green transformation. Financial leverage (*Lev*) is measured by the total asset-to-liability ratio, and firm profitability is measured by return on total assets (*ROA*). Ownership concentration (*Top1*) is represented by the shareholding ratio of the largest shareholder. Firm size is calculated as the natural logarithm of total assets. The listing age (*ListAge*) is defined as the number of years since the firm's initial public offering. Board independence (*Indep*) is the proportion of independent directors among the total board members. Institutional shareholding (*INST*) is the ratio of shares held by institutional investors to total share capital. Management shareholding (*Mshare*) is the share percentage held by directors and supervisors relative to total share capital. Tobin's Q (*TobinQ*) measures a firm's market valuation relative to its capital replacement cost. Major shareholders' fund occupation (*Occupy*) is measured by the ratio of net remaining receivables to total assets.

4. Empirical results

4.1 Baseline results

This research evaluates the impact of ESG ratings on enterprises' green innovation. This paper uses model (1) for the baseline analysis, and the results are shown in Table 2. This specification controls for both enterprise and year fixed effects, with standard errors clustered at the enterprise level. The results in Table 2 show that ESG ratings have a robust positive impact, indicating that these ratings significantly improve enterprises' green innovation efficiency. After incorporating a comprehensive set of control variables, the coefficient on the ESG ratings is 0.005, which is statistically significant at the 1% level. This coefficient translates to an average 0.5% increase in enterprises' green innovation efficiency in the subsequent year, an effect directly attributable to ESG ratings. The underlying reason for this positive effect may be that ESG ratings improve enterprise transparency through multi-dimensional information disclosure, effectively alleviating information asymmetry caused by incomplete contracts. They also reduce stakeholders' oversight costs, enhance their willingness to monitor, and force enterprises to rectify unsustainable business practices and continuously increase green innovation investment, thus validating H1. Control variable regression results show that after controlling for enterprise and year fixed effects, most enterprise-level controls have no significant effect on enterprise green innovation efficiency; *Top1* and *Occupy* are significantly negative, indicating that higher ownership concentration and major

shareholders' fund occupation hinder enterprise green innovation, as both deplete the resources and risk appetite critical to green innovation.

Table 1. Baseline results

	(1)	(2)
	GreenInnov	GreenInnov
<i>ESG</i>	0.005*** (0.001)	0.005*** (0.001)
<i>Lev</i>		-0.002 (0.003)
<i>ROA</i>		-0.001 (0.007)
<i>Top1</i>		-0.000* (0.000)
<i>ListAge</i>		-0.002 (0.001)
<i>Indep</i>		-0.000 (0.000)
<i>INST</i>		-0.003 (0.002)
<i>Mshare</i>		0.000 (0.000)
<i>TobinQ</i>		0.000 (0.000)
<i>Occupy</i>		-0.053** (0.023)
Observations	24,499	24,499
R-squared	0.6645	0.6849
Firm FE	YES	YES
Year FE	YES	YES
Adjust R-squared	0.6117	0.6271

Note: *, **, and *** denote significance at the 10%, 5%, and 1% levels. The values in parentheses represent robust standard errors clustered at the enterprise level.

Source: Authors' processing.

4.2 Robustness Test

4.2.1 Parallel Trend Test

The DID model utilised in this study requires the Parallel Trend Assumption to hold for unbiased results. This core assumption stipulates that, prior to the introduction of ESG ratings, the treatment group (rated enterprises) and control group (non-rated enterprises) exhibit similar trends in green innovation efficiency – ensuring that post-treatment trend differences can be attributed to ESG ratings rather than pre-existing disparities. As shown in Fig.1, no significant difference in green innovation efficiency exists between the two groups before ESG ratings are implemented, verifying the Parallel Trend Assumption. After ESG ratings are introduced, the treatment group's green innovation efficiency significantly surpasses that of the control group. This confirms that ESG ratings exert a positive and

significant impact on enterprises' green technology innovation, validating their effectiveness in promoting environmental innovation practices.

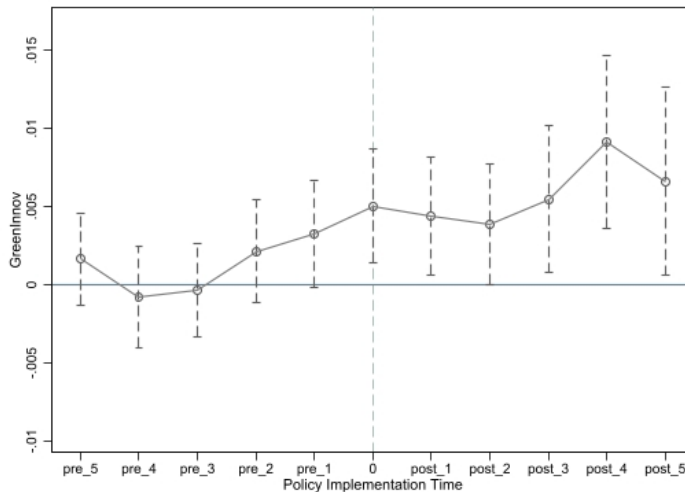


Figure 1. Parallel trend test
 Source: Authors' own creation.

4.2.2 Placebo test

To ascertain that the influence of ESG ratings on the efficiency of green innovation within enterprises is not confounded by external factors, this research employed a placebo test. This test was designed to determine the stability of the observed effects, thereby validating the causative relationship between ESG ratings and green innovation efficiency. For the test, 500 samples were randomly selected according to the distribution of ESG rating variables from the initial regression analysis to create 'pseudo-policy dummy variables'. These variables were used to execute a reanalysis of model (1), facilitating a comparison of coefficient magnitudes and the distribution of P-values. The results, depicted in Figure 2, indicate that the average regression coefficients in the 'pseudo-policy dummy variables' approach zero, markedly lower than those in the initial regression. Furthermore, the distribution of these coefficients approximates a normal curve, with most P-values surpassing 0.10, indicating no significant statistical relevance at the 10% threshold. These findings confirm that the notable impacts of ESG ratings on green innovation efficiency are not merely coincidental, enhancing the validity of the research conclusions.

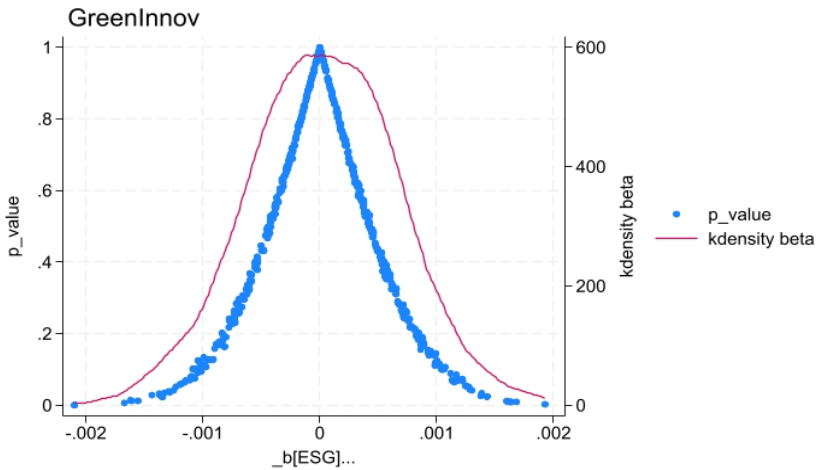


Figure 2. Placebo test
 Source: Authors' own creation.

4.2.3 PSM-DID

Given concerns about potential bias in ESG rating disclosures favouring larger enterprises with more detailed disclosures, the study employed Propensity Score Matching (PSM) to address potential sample selection biases. The findings, presented in Table 2's first column, show a regression coefficient of 0.004 for ESG ratings at a 1% significance level, underscoring their critical influence on enhancing green innovation efficiency in enterprises. Moreover, these results suggest that the initial model is free from significant sample selection bias, thereby affirming the robustness of the conclusions.

4.2.4 Changing the sample interval

The COVID-19 pandemic's emergence in late 2019 profoundly affected the global economy and adversely impacted key enterprises in the Chinese market. To avoid distortions in our analysis of green innovation efficiency improvements in Chinese enterprises due to the pandemic, the 2020 data were omitted from this study. Subsequent analysis reevaluates the influence of ESG ratings on green innovation efficiency. According to the regression analysis shown in Table 2's second column, the ESG rating coefficient stands at 0.004, significant at the 1% level, indicating that ESG ratings positively contribute to enhancing green innovation efficiency in enterprises.

4.2.5 Substitution of variables

To enhance the robustness of the findings that ESG ratings positively affect green innovation efficiency in enterprises, this study substitutes the primary explanatory variables with data from the Huazheng ESG rating system. This system provides comprehensive coverage of Chinese enterprises, offering a broader

perspective on ESG performance across different sectors. The Huazheng ESG ratings are directly incorporated as the core explanatory variable in the analysis, assigning values from 1 to 9 to the nine rating grades. A higher value indicates a superior ESG rating. Regression results from Table 2's third column indicate that the Huazheng ESG rating coefficient is 0.0012, achieving statistical significance at the 1% level. This outcome supports the preliminary findings, confirming a positive correlation between elevated ESG ratings and enhanced efficiency in green innovation. The use of Huazheng ESG data not only validates the previous findings, but also underscores the consistency of ESG ratings' impact across different data sets and rating systems, thus strengthening the evidence that ESG ratings are a significant driver of green innovation in enterprises.

Table 2. Regression results

	(1) GreenInnov	(2) GreenInnov	(3) GreenInnov
<i>ESG</i>	0.004*** (0.001)	0.004*** (0.001)	
<i>HuaZhengESG</i>			0.001*** (0.001)
<i>Lev</i>	-0.002 (0.003)	-0.003 (0.003)	-0.001 (0.003)
<i>ROA</i>	-0.003 (0.007)	-0.002 (0.008)	-0.006 (0.007)
<i>Top1</i>	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)
<i>ListAge</i>	-0.002 (0.002)	-0.001 (0.002)	-0.002 (0.001)
<i>Indep</i>	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)
<i>INST</i>	-0.002 (0.002)	-0.003 (0.002)	-0.002 (0.002)
<i>Mshare</i>	0.000 (0.000)	-0.000 (0.000)	0.000 (0.000)
<i>TobinQ</i>	-0.000 (0.000)	-0.000 (0.000)	0.000 (0.000)
<i>Occupy</i>	-0.050** (0.023)	-0.060** (0.024)	-0.045** (0.022)
Observations	19031	16838	19683
R-squared	0.677	0.700	0.685
Firm FE	YES	YES	YES
Year FE	YES	YES	YES
Adjust R-squared	0.616	0.632	0.623

Source: Authors' processing.

5. Mechanism analysis

5.1 Executive green cognition

Executive Green Cognition (*EGC*) refers to the executives' psychological cognition of resource and environmental issues, which contains three core

dimensions: recognition of green competitive advantages, commitment to social responsibility, and sensitivity to external environmental pressures. This study examines the mediating role of *EGC* in the causal link between ESG ratings and green innovation efficiency. For the core mediating variable, this study innovatively constructs a refined, objective metric for *EGC*. Specifically, we quantify *EGC* using the frequency of keywords corresponding to its three core dimensions in the annual reports of listed enterprises. This measurement approach provides a direct and quantifiable proxy for the executives' implicit environmental awareness and strategic orientation, addressing the subjective bias limitation of traditional *EGC* measurement methods. To test the mediating effect of *EGC*, we employ the Bootstrap method with 3000 repeated resamples. The empirical results in Table 3 show that the indirect effect ($a*b$) of ESG ratings on green innovation efficiency through *EGC* is 0.00024, with a 95% confidence interval of [0.00015, 0.000473] that does not contain zero. This result confirms that the partial mediating effect of *EGC* is statistically significant: ESG ratings can significantly improve enterprises' green innovation efficiency by raising executive green cognition. This finding fully validates H2, confirming that ESG-driven enhancement of executive green cognition is a key channel to boost green innovation efficiency.

The underlying rationale for this mechanism is that the growing attention from media and investors to corporate ESG performance amplifies the reputational, market, and regulatory incentives for executives to prioritise environmental governance. This external scrutiny reshapes executives' strategic cognition, drives them to adopt proactive eco-friendly strategies, and ultimately translates into higher green innovation efficiency.

5.2 Financing constraints

This study tests the mediating role of financing constraints between enterprise ESG ratings and green innovation efficiency. We measure corporate financing constraints with the *FC* index (ranging from 0 to 1), where a higher value indicates tighter enterprise financing pressure. We test the mediating effect using the Bootstrap method with 3000 resamples. Results reported in Table 3 show that the indirect effect ($a*b$) of ESG ratings on green innovation efficiency via financing constraints is -0.00011, with a 95% confidence interval [-0.000194, -0.000023] that excludes zero. This confirms a statistically significant partial mediating effect: ESG ratings significantly improve enterprise green innovation efficiency by alleviating financing constraints, which validates H3.

The core logic of this mechanism is that strong ESG performance mitigates information asymmetry between enterprises and external investors, helps enterprises access low-cost green financing and attract green investors, thus easing financing constraints and providing stable financial support for green innovation activities.

5.3 R&D investment

This study tests the mediating role of R&D investment between enterprise ESG ratings and green innovation efficiency. We measure enterprise R&D investment with two indicators: total R&D expenditure (*RDExp*) and the ratio of R&D expenditure to operating revenue (*RDSales*). We test the mediating effect using the Bootstrap method with 3000 independent resamples. The results reported in Table 3 show that: for *RDExp*, the indirect effect ($a*b$) is 0.00325, with a 95% confidence interval [0.00269, 0.0038] excluding zero; for *RDSales*, the indirect effect ($a*b$) is 0.00130, with a 95% confidence interval [0.00093, 0.00168] also excluding zero. Both indicators confirm a statistically significant mediating effect: ESG ratings improve enterprise green innovation efficiency by boosting R&D investment, which validates H4.

The core logic of this mechanism is that ESG ratings drive enterprises to internalise the externalities of R&D activities, integrate environmental and social responsibility into operational decision-making, thus incentivising greater R&D input that provides core resource support for green technology innovation and ultimately improves green innovation efficiency.

Table 3. Bootstrap mechanism test results

		Observed coefficient	Bootstrap std.err	Z	P> Z	Normal-based [95% conf.Interval]	
<i>ESG</i> → <i>EGC</i> → <i>GreenInnov</i>	Indirect effect	.0002399**	.0001193	2.01	0.044	.0001499	.0004737
	Direct effect	.014539***	.0009863	14.74	0.000	.0126059	.0164722
	Total effect	.014779***	.0009882	14.96	0.000	.0128422	.0167158
<i>ESG</i> → <i>FC</i> → <i>GreenInnov</i>	Indirect effect	-.0001082**	.0000437	-2.48	0.013	-.0001938	-.0000225
	Direct effect	.0055593***	.0012658	4.39	0.000	.0030784	.0080403
	Total effect	.0054512***	.0012673	4.30	0.000	.0029673	.007935
<i>ESG</i> → <i>RDExp</i> → <i>GreenInnov</i>	Indirect effect	.0032455***	.0002833	11.46	0.000	.0026902	.0038008
	Direct effect	.0022058*	.00124	1.78	0.075	-.0002245	.004636
	Total effect	.0054513***	.001263	4.32	0.000	.0029758	.0079267
<i>ESG</i> → <i>RDSales</i> → <i>GreenInnov</i>	Indirect effect	.0013012 ***	.0001914	6.80	0.000	.000926	.0016764
	Direct effect	.0041501***	.0013161	3.15	0.002	.0015706	.0067295
	Total effect	.0054513***	.001328	4.10	0.000	.0028484	.0080541

Source: Authors' processing.

6. Heterogeneity analysis

6.1 Enterprise pollution levels

Against the backdrop of China's consecutive rollout of green credit and green finance policies in recent years, which have created differentiated regulatory constraints and financing incentives for enterprises with varying environmental impacts, the transmission mechanism of ESG ratings may differ significantly

between polluting and non-polluting enterprises. To identify the industry heterogeneity in the impact of ESG ratings on enterprise green innovation efficiency, we divide the full sample into two groups: polluting enterprises (*Pollute*) and non-polluting enterprises (*NPollute*), and conduct grouped regression analysis. The regression results in Table 4 show that the coefficients of ESG ratings are significantly positive for both groups, indicating that ESG ratings can significantly improve the green innovation efficiency of both types of enterprises. Among them, the coefficient for polluting enterprises is significantly positive at the 1% level, with a more prominent driving effect. This heterogeneity result mainly stems from the fact that polluting enterprises face higher environmental risks and financing constraints. The improvement of ESG performance can more effectively release green transformation signals, ease financing frictions, and unlock greater marginal space for green innovation, thus bringing a stronger innovation promotion effect.

6.2 Type of enterprise element

The factor intensity of an enterprise determines its core resource endowment, production and operation mode, and innovation strategy orientation. Enterprises with different factor intensities have systematic differences in the resource base, transformation demand, and constraint conditions of green innovation, so the driving effect of ESG ratings on their green innovation efficiency may present significant heterogeneity. To this end, we divide the full sample into three groups: labour-intensive enterprises (*Labor*), asset-intensive enterprises (*Asset*) and technology-intensive enterprises (*Technology*) according to factor intensity, and test the above heterogeneous impact through grouped regression. The regression results in columns 3 to 5 of Table 4 show that the coefficients of ESG ratings are significantly positive in the labour-intensive and asset-intensive enterprise groups, while the coefficient is positive but insignificant in the technology-intensive enterprise group. This indicates that the promotion effect of ESG ratings on enterprise green innovation efficiency is mainly reflected in labour-intensive and asset-intensive enterprises, with significant factor intensity heterogeneity. The core reason for this result is that labour-intensive and asset-intensive enterprises have a relatively weak foundation for green innovation and face stronger environmental compliance and transformation pressure. The improvement of ESG ratings can more effectively release policy and financing dividends, bringing a stronger marginal driving effect on green innovation. On the contrary, technology-intensive enterprises have high R&D investment and a solid innovation foundation, so the marginal incremental effect of ESG on their green innovation is relatively limited.

Table 4. Enterprise pollution levels, type of enterprise element

	GreenInnov		GreenInnov		
	(1) Pollute	(2) NPollute	(3) Labor	(4) Asset	(5) Technology
<i>ESG</i>	0.010***	0.003**	0.005**	0.011***	0.002

	GreenInnov		GreenInnov		
	(1) Pollute	(2) NPollute	(3) Labor	(4) Asset	(5) Technology
	(0.001)	(0.017)	(0.020)	(0.000)	(0.237)
<i>Lev</i>	-0.000 (0.007)	-0.002 (0.003)	-0.006 (0.004)	0.006 (0.008)	0.003 (0.002)
<i>ROA</i>	0.021 (0.016)	-0.013 (0.008)	-0.017 (0.011)	0.024 (0.019)	-0.007 (0.011)
<i>Top1</i>	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)
<i>ListAge</i>	-0.004 (0.004)	-0.002 (0.002)	0.001 (0.002)	-0.006 (0.005)	-0.004 (0.002)
<i>Indep</i>	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	0.000 (0.000)	-0.000 (0.000)
<i>INST</i>	0.002 (0.004)	-0.002 (0.002)	0.000 (0.003)	-0.002 (0.006)	-0.001 (0.003)
<i>Mshare</i>	0.000 (0.000)	-0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	-0.000 (0.000)
<i>TobinQ</i>	0.001 (0.001)	-0.000 (0.000)	-0.000 (0.000)	0.001 (0.001)	-0.000 (0.000)
<i>Occupy</i>	-0.076* (0.044)	-0.042 (0.027)	-0.009 (0.033)	-0.118** (0.055)	-0.063* (0.035)
Year FE	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES
Observations	4,677	14,965	5,683	3,412	10,221
Adjust R-squared	0.547	0.649	0.575	0.536	0.656

Source: Authors' processing.

6.3 Green investors

Investors are key stakeholders that transmit the capital market impact of ESG ratings to enterprise micro-innovation decisions, and there are essential differences in investment philosophy, value orientation, and risk preference between green and non-green investors. The two types of investors differ significantly in their attention to enterprise ESG performance and their willingness to support green innovation activities, which may lead to heterogeneous effects of ESG ratings on enterprise green innovation efficiency. To test this potential heterogeneity, we divide the full sample into two groups according to whether the enterprise has green investors, and conduct grouped regression analysis. The regression results in columns 1 and 2 of Table 5 show that the coefficient of ESG ratings is significantly positive in the group of enterprises with green investors, while the effect is insignificant in the group without green investors. This indicates that the promoting effect of ESG ratings on enterprise green innovation efficiency is significantly more prominent among enterprises with green investors. The core reason for this result is that green investors with ESG-aligned investment philosophy can not only provide stable low-cost financing support for the green innovation of high-ESG enterprises, but also play a shareholder governance role to urge enterprises to increase green innovation investment, thus amplifying the driving effect of ESG ratings. In contrast, non-green investors focusing on short-term returns fail to form such a synergistic effect.

6.4 Geographic location

There are significant gradient differences in economic development level, financial market maturity, and green innovation factor endowment across the eastern, central and western regions of China. This inherent regional heterogeneity will directly affect the transmission mechanism and effect intensity of ESG ratings on enterprise green innovation efficiency. To test the regional heterogeneity of the impact of ESG ratings, we divide the full sample into three groups according to the geographical location of the enterprise's registered place: east (*East*), mid (*Mid*), and west (*West*), and conduct grouped regression analysis. The regression results in columns 3 to 5 of Table 5 show that the coefficients of ESG ratings are positive but insignificant for enterprises in central and western China, while the coefficient is significantly positive at the 1% level for enterprises in eastern China. This indicates that the promoting effect of ESG ratings on enterprise green innovation efficiency is mainly concentrated in eastern China, with obvious regional heterogeneity. The core reason for this result is that the eastern region has a more developed green financial system, sufficient ESG-focused investors, and a sound innovation supporting environment. The improvement of ESG ratings can more effectively alleviate financing constraints and release innovation incentives, thus significantly driving green innovation. In contrast, the central and western regions have limited financial resources and innovation-supporting conditions, so the driving effect of ESG ratings cannot be fully exerted.

6.5 Degree of openness

The degree of external openness of an enterprise directly determines its ability to access global innovation resources. Enterprises with different levels of openness have systematic differences in resource endowment, incentive mechanisms, and constraint conditions for green innovation, which may lead to significant heterogeneity in the driving effect of ESG ratings on enterprise green innovation efficiency. To test this potential heterogeneous impact, we divide the full sample into two groups for grouped regression analysis according to the level of regional openness where the enterprise is located. Enterprises registered in 20 centrally designated open coastal cities or Special Economic Zones are classified into the high openness group (*HOpen*), and all other enterprises are classified into the low openness group (*LOpen*). The regression results in columns 6 and 7 of Table 5 show that the coefficient of ESG ratings is positive but insignificant for high-openness enterprises, while the coefficient is significantly positive at the 1% level for low-openness enterprises. This indicates that the promoting effect of ESG ratings on enterprise green innovation efficiency is mainly concentrated in low-openness enterprises. The core reason for this result is the resource compensation effect of ESG ratings. High-openness enterprises can conveniently access global innovation resources through their location advantages, so the marginal driving effect of ESG

ratings is limited. Low-openness enterprises face strong resource constraints due to location restrictions, and the improvement of ESG ratings can help them broaden financing channels, attract green capital, make up for resource shortcomings, and thus significantly improve their green innovation efficiency.

Table 5. Green investor, geographic location, degree of openness

	<i>GreenInnov</i>		<i>GreenInnov</i>			<i>GreenInnov</i>	
	(1) GreInvestor	(2) NGreInvestor	(3) West	(4) Mid	(5) East	(6) HOPne	(7) LOpen
<i>ESG</i>	0.004** (0.011)	0.003 (0.200)	0.003 (0.277)	0.005 (0.116)	0.005*** (0.000)	0.003 (0.155)	0.006*** (0.000)
<i>Lev</i>	0.000 (0.006)	-0.003 (0.004)	0.005 (0.008)	0.005 (0.007)	-0.004 (0.004)	-0.011** (0.006)	0.003 (0.003)
<i>ROA</i>	0.013 (0.014)	-0.021** (0.010)	-0.005 (0.020)	0.030 (0.022)	-0.010 (0.008)	-0.021 (0.014)	0.003 (0.009)
<i>Top1</i>	0.000 (0.000)	-0.000** (0.001)	-0.000 (0.000)	0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.001)
<i>ListAge</i>	0.003 (0.003)	-0.006*** (0.002)	-0.011** (0.005)	-0.005 (0.004)	0.000 (0.000)	0.002 (0.003)	-0.004** (0.002)
<i>Indep</i>	0.000 (0.000)	-0.000 (0.000)	0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	0.000 (0.000)	-0.000 (0.000)
<i>INST</i>	-0.004 (0.004)	0.002 (0.003)	0.000 (0.006)	0.001 (0.006)	-0.002 (0.002)	-0.006 (0.004)	0.001 (0.002)
<i>Mshare</i>	0.000 (0.000)	0.000 (0.000)	-0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	-0.000 (0.000)	0.000 (0.000)
<i>TobinQ</i>	-0.000 (0.001)	0.000 (0.001)	0.000 (0.000)	0.000 (0.001)	-0.000 (0.000)	0.000 (0.001)	-0.000 (0.001)
<i>Occupy</i>	-0.111** (0.051)	0.004 (0.027)	-0.070 (0.062)	0.016 (0.054)	-0.052* (0.027)	-0.052 (0.041)	-0.043 (0.027)
Year FE	YES	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES	YES
Observations	8,079	10,026	3,173	2,402	14,096	5,622	14,050
Adjust R-squared	0.670	0.577	0.625	0.585	0.635	0.639	0.624

Source: Authors' processing.

7. Conclusions and suggestions

Taking the initial release of Environmental, Social and Governance (ESG) ratings for Chinese listed enterprises by SynTao Green Finance as an exogenous shock, this study empirically examines the causal effect of ESG ratings on enterprise green innovation with a multi-period difference-in-differences model, using a panel dataset of Chinese A-share listed enterprises covering 2010 to 2021. The main findings are summarised as follows: First, ESG ratings significantly improve the efficiency of enterprise green innovation. Second, the mechanism test results further demonstrate that the promotional effect of ESG ratings on enterprise green innovation efficiency is realised through three core transmission channels: raising executives' green cognition, alleviating enterprise financing constraints, and increasing enterprise R&D investment. Third, the heterogeneity analysis reveals that

the positive impact of ESG ratings on enterprise green innovation efficiency has significant group and regional heterogeneity. The facilitating effect is more prominent for heavily polluting enterprises, labour-intensive enterprises, and asset-intensive enterprises. Meanwhile, ESG ratings exert a stronger empowering effect on green innovation for enterprises held by green investors, enterprises located in western China, and enterprises in regions with a high degree of openness. This study confirms that ESG ratings exert a significant positive promoting effect on the green innovation efficiency of enterprises, a finding that is highly consistent with mainstream research conclusions in the field of ESG and enterprise green innovation. The existing literature has extensively verified that ESG ratings can drive green innovation outputs in multiple dimensions, including output volume, spatial spillover effects, achievement quality, and innovation sustainability (Long et al., 2023; Li et al., 2023; Liu & Xu, 2024; Shan et al., 2025). Building on these findings, this study further expands the research boundaries of ESG-enabled green innovation, verifies its promoting effect on green innovation efficiency, and supplements core empirical evidence from the efficiency dimension to clarify the intrinsic relationship between ESG and enterprise green innovation.

Based on the above conclusions, this paper proposes the following policy recommendations. (1) Improve the ESG rating institutional system. Regulators should accelerate the unification of ESG information disclosure and rating standards, introduce differentiated guidance for heavily polluting, labour-intensive, and asset-intensive enterprises, and strengthen the market-based incentive and constraint functions of ESG ratings. (2) Guide enterprises to embed ESG into operational strategies. Enterprises should be encouraged to enhance management's green cognition, scale up green R&D investment, and leverage ESG ratings to ease financing constraints, thus unlocking the endogenous momentum of green innovation. (3) Foster a green capital market ecosystem. Institutional investors should be guided to practice the green investment philosophy, expand the scale of green investors, and give full play to the capital market's role in supporting and supervising enterprise ESG practices and green innovation. (4) Optimise regional policy design tailored to local conditions. Targeted supporting policies should be implemented in western China and high-openness regions to amplify the positive effect of ESG ratings, facilitating a regional green and low-carbon transition.

This paper has the following limitations: the study focuses on the Chinese market, and, while it can accurately identify the net effect of ESG ratings, it has certain limitations. Future research will include multinational corporations and compare the different effects of ESG ratings in developed and emerging economies.

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