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Do ESG Scores in Corporations Improve Green Innovation? Empirical Evidence from Listed Chinese Companies

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Abstract: The ESG score system is a fundamental component of the green financial system that is essential in promoting corporate environmental progress. In this work, we investigate the micro-environmental impact of ESG scores using panel fixed effects models. We examine the processes underlying the influence of ESG scores on the performance of corporate green innovation, as well as any potential inequalities in this impact under different moderating factors. To conduct our analysis, we use data from Chinese-listed A-shares on the Shanghai and Shenzhen stock exchanges from 2010 to 2019. Our study demonstrates a relationship between corporate green innovation and ESG ratings, indicating that higher ESG ratings assist businesses in achieving better green innovation results. This beneficial effect is evident both numerically and qualitatively, and it continues to hold up even after being put through several demanding tests. Additionally, we pinpoint two main ways that ESG encourages corporate green innovation: by boosting government-enterprise ties and strengthening corporate investment efficiency. We also note that while business characteristics aligned with sustainability further enhance the favorable influence of ESG on green innovation performance, characteristics linked to ecologically detrimental activities impede the contribution of ESG to green innovation. Our study adds to the body of knowledge already available on corporate environmental performance and green finance by offering empirical insights that can help enhance corporate environmental development and improve the ESG rating system.

Keywords: ESG; Green innovation; Investment efficiency; Government-business relationship; Environmental features

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1. Introduction

By generating innovative goods, procedures, and techniques that reduce environmental dangers, pollution, and resource consumption throughout their life cycles, green innovation focuses on developing sustainable solutions[1-3]. It is a crucial way for firms to adopt the Environment, Social, and Governance (ESG) paradigm and promote long-term change in their industries[4]. Low carbon footprint, energy efficiency, and efficacy are the hallmarks of green inventions[5]. They do, however, also carry long-term risks, deliver public services, and produce advantageous environmental externalities[6]. The effects of industrialization and economic globalization on the environment are getting worse as they progress. Extreme climate events and environmental pollution problems are aggravating. In this context, green innovation becomes an indispensable approach to reconciling the conflicts between human activities and

the environment[7-8].

Several variables play a pivotal role in determining the effectiveness of corporate green innovation, thereby assisting organizations in maintaining their competitive advantage and enhancing corporate value. Academic studies have identified four main categories of influencers on green innovation. The first category pertains to market elements, encompassing factors such as competitive pressure, consumer demand for green products, the accessibility of financial markets, and certification for environmental labeling[9-14]. Corporate green innovation can benefit from media support and public social supervision[15]. The second category revolves around environmental policies. Research has revealed mixed findings, with some studies indicating that initial environmental regulations may constrain corporate green innovation, while subsequently supporting it[17-18]. Various pilot initiatives, including emissions trading[19], environmentally friendly pilot policies[20-21], emissions allowance systems[22-24], carbon dioxide trading platforms[23-24], green credit schemes[25-27], environmentally friendly manufacturing audit programs[28], and disclosure of environmental data systems[29-32], have been found to encourage businesses to adopt green innovation. The third category involves the interaction between businesses and politics, which manifests through government funding and political alliances. Politics can hinder green innovation in businesses, particularly when the market is relatively small[33]. On the other hand, political affiliations can stimulate companies' green innovation by augmenting research and development (R&D) expenditure and organizational resources, in addition to subsidies that can enhance corporate green innovation performance[34-35]. However, some research suggests a limited connection between corporate subsidies and green innovation[36]. Lastly, internal company factors strongly support the development of green business innovation. These factors include responsible leadership by the CEO[3], executive academic experience[37], sustainability objectives[38], corporate social responsibility (CSR) performance[4], and internal rules of institutional investors.

By considering these various influences, organizations can better comprehend and leverage the factors that contribute to successful corporate green innovation, leading to sustainable competitive advantages and enhanced corporate value. ESG evaluation evaluates firms based on environmental, social, and internal management factors, and can be viewed as an expansion of the concept of corporate social responsibility[39]. This assessment shows a company's level of environmental transformation and its environmental reputation[40]. ESG has also become a popular investment idea, and as a result, ESG considerations are now included in investment portfolios. As a result, businesses, investors, and financial institutions around the world now agree on the ESG concept[41-42]. ESG has gradually been included in company plans and has emerged as a crucial indication of corporate green development[43-44]. The majority of current research focuses on the connection between ESG and corporate performance. Some contend that ESG has no bearing on a company's profitability or cost of capital and may even be detrimental to its performance[68]. However, according to other research findings, greater ESG scores can help businesses overcome their financing challenges and perform better overall[46-49]. Additionally, better stock returns, more stock liquidity, and a lower risk of market collapses are all linked to higher ESG ratings[50-51]. Additionally, it has been discovered that ESG ratings improve innovation performance, which then increases organizational value[52-53]. However, there are competing viewpoints that contend ESG has a negative impact on business value[54].

The relationship between corporate ESG performance and corporate green innovation has only received a tiny amount of research. The number and quality of corporate green innovation are positively impacted by social responsibility institutions and performance, according to some studies that have mostly focused on this aspect of business[4,55]. Though it is only one part of the bigger picture, the social responsibility

perspective by itself cannot accurately represent a company' s entire ESG performance. Even though minimal research has particularly looked at the connection between ESG and green innovation utilizing ESG rating information for Chinese enterprises, these studies have several drawbacks[56]. First off, because unrated enterprises were included in the sample and because rated firms naturally do better financially and environmentally than unrated ones, their main regression strategy, which employs ratings as a quasi-natural experiment, is not very credible. Because of the endogeneity problems in their empirical models, they cannot be regarded as genuine quasi-natural experiments. Additionally, the grouping technique used is not reliable. Second, they also talk about the effect of particular ESG ratings on businesses' green innovation, though with a considerably lower sample size than the regression analysis stated before. Additionally, the slight changes in ratings do not sufficiently reflect the variability in business ESG performance, raising questions about the validity of their judgments.

The comprehensive understanding of the intricate relationship between Environmental, Social, and Governance (ESG) performance and its impact on various business aspects, including innovation, performance, share prices, and enterprise value, is paramount. It becomes imperative to comprehend the influence of ESG ratings on corporate green innovation, considering the underlying mechanisms and potential imbalances, to foster sustainable economic development and facilitate corporate transformation amid environmental degradation and resource depletion. In this empirical study, we develop a statistical model using ESG scores from 2010 to 2019 and data on the quantity and quality of green innovations from 2011 to 2020 to examine this relationship in the context of Chinese companies listed on the Shanghai and Shenzhen stock exchanges. Our empirical findings provide support for our research hypothesis, revealing a positive association between firm ESG performance and green innovation. Specifically, we identify two key mechanisms through which ESG ratings facilitate green innovation: enhancing political and commercial connections and improving investment efficiency. Moreover, we observe that the impact of ESG on green innovation performance is more pronounced in companies with stronger environmental qualities, while it is comparatively weaker in companies facing greater environmental challenges. To measure ESG, we employ Bloomberg ESG Disclosure Scores, which are independently published by a non-Chinese entity, ensuring a more objective evaluation of organizations' ESG performance. The utilization of score data also addresses the limitations of previous grading methods, which may be prone to inaccuracies and errors in assessing ESG performance. Overall, our study elucidates the underlying mechanisms and moderating factors in the relationship between firm ESG scores and green innovation. These findings hold practical implications for the advancement of the ESG rating system and the promotion of business green development.

Our research makes a significant contribution in several ways, distinguishing itself from previous studies. Firstly, we address the limitations present in prior research by adopting ESG score variables instead of relying solely on the original ESG ratings. This refinement increases the precision and accuracy of evaluating ESG performance[56]. Secondly, we assess the quantity and quality of green innovation as a measure of the effectiveness of the ESG evaluation method. Previous studies on ESG have predominantly focused on corporate performance, stock prices, and value, largely overlooking the environmental and green dimensions of ESG. Similarly, research on green innovation has primarily emphasized quantitative aspects, neglecting considerations of quality. By incorporating the relevant ESG components that pertain to green innovation and utilizing quantitative metrics that encompass the quality of green innovation, our study provides a more comprehensive perspective. Thirdly, we delve into the mechanisms through which ESG influences green innovation and examine the variations in this influence based on the regulatory context. We investigate the impact of ESG on the investment effectiveness of green innovation and consider the role of public-private partnerships in promoting green innovation. Additionally, we analyze the

asymmetry in the influence of ESG on green innovation by accounting for the characteristics of both the green and black markets. Our study advances the field by refining the evaluation of ESG, encompassing both the quantitative and qualitative aspects of green innovation, exploring underlying mechanisms and moderating effects, and acknowledging asymmetries in the impact of ESG on green innovation. These contributions deepen our understanding of the relationship between ESG and green innovation, offering valuable insights for businesses, researchers, and policymakers.

The paper is organized as follows: Section 2 provides a comprehensive theoretical background and introduces the research hypotheses that guide our investigation. In Section 3, we present the model design, outlining the conceptual framework and specifying the variables of interest. Additionally, we describe the rigorous data selection technique employed to ensure the reliability and validity of our analysis. The empirical findings are presented and thoroughly examined in Section 4, where we analyze the statistical results in relation to our research questions and hypotheses. To ensure the robustness of our conclusions, we conduct a series of rigorous tests and sensitivity analyses, which are presented in Section 5. These robustness tests assess the stability and consistency of our findings, further enhancing the credibility of our research. Finally, Section 6 concludes the paper by synthesizing the key findings, discussing their implications, and providing avenues for future research. The concluding section also offers a comprehensive reflection on the research objectives and highlights the practical implications for businesses, researchers, and policymakers in the context of environmental deterioration and resource depletion.

2. Theoretical framework and hypotheses development

2. 1. ESG and green innovation

Whether it entails technologically based green innovation initiatives or business strategies that are focused on the market, businesses now value their relationship with corporate stakeholders[57]. They put more emphasis on developing integrated values that cover social, environmental, and economic factors because these factors are all intimately tied to the success of ESGs[9]. The term "green innovation" refers to efforts made by companies to use resources more effectively, consume less energy, and apply cutting-edge methods to accomplish both economic and environmental goals[1]. Companies can lower emissions and use less energy by developing green processes and products[2, 58].

ESG exerts a significant influence on corporate green innovation in three key areas. Firstly, the environmental responsibility of businesses plays a crucial role in driving green innovation initiatives. With stringent environmental regulations and heightened public expectations, companies face mounting pressure to enhance their environmental performance and cultivate a positive environmental reputation. To meet these demands, businesses are compelled to adopt green innovation technologies, improve their production processes, and embrace cleaner manufacturing practices. By integrating these innovations, companies can enhance their environmental performance, achieve energy efficiency, and reduce emissions. Additionally, robust environmental performance can alleviate financial constraints, leading to lower financing costs for businesses[59], thereby bolstering their capacity for green innovation.

Furthermore, CSR encourages green innovation by strengthening stakeholder relationships and offering the tools and data required for green innovation initiatives. Stakeholder theory asserts that actively pursuing social responsibility aids businesses in forging closer ties with a range of stakeholders, including regulators, institutional investors, and the general public. These connections enable businesses to have access to the financial and commercial resources needed for green innovation, hence fostering green enterprise innovation[30]. Signaling theory claims that corporate social responsibility has an "information

effect" that reduces information asymmetry and principal-agent issues while supplying useful data to support businesses' long-term decisions regarding their engagement in green innovation activities. They can then produce more green patents as a result[60].

Thirdly, strong internal governance has a beneficial impact on how well corporate green innovation performs[61]. Green innovation initiatives can involve higher risks and longer cycles, which may deter businesses from choosing to invest in innovation. However, effective corporate governance reduces principal-agent conflicts through mechanisms for incentives and restraints. As a result, corporate management decides to invest more money in R&D and innovation, which helps the company develop sustainably over the long term[62-63]. Furthermore, strong internal governance improves overall business performance by mobilizing internal and external resources to provide a stable and sustainable financial foundation for ongoing green innovation efforts.

ESG factors also support businesses in embracing sustainable development concepts and encouraging innovative growth[64]. On the one hand, these principles urge businesses to work toward initiatives like clean production, emission reduction, and energy conservation. In turn, this encourages them to boost their investments in innovation and embrace technology throughout their operating and manufacturing processes that save energy and safeguard the environment[65]. On the other hand, businesses that are guided by green concepts direct their funding toward green initiatives through green financing, enabling a change in internal capital flows that is environmentally and climate-friendly. In order to provide strong support for activities, such as green innovation, they may also allocate investment dollars into greener initiatives. These programs act as impetuses for promoting business innovation in the green sector.

Based on our research, we formulated the following research hypothesis:

(H1) There is a positive correlation between ESG and corporate green innovation.

Since the conception of this idea, important themes have included the definition of a "Master Teacher" and the development and study of a "Master Teacher Studio." The main problem and the biggest hurdle in developing and researching a "Master Teacher Studio" is precisely defining what a "Master Teacher" is. A "Master Teacher Studio" is supposedly led by outstanding teachers in a particular field, according to the 2016 Report on the Development of Master Teacher Studios in China. It gathers a community of exceptional teachers that share similar educational ideas and pursuits, have professional credentials, and have made significant contributions to the same field in order to build a brand of educational talent. The studio utilizes educational research, base activities, and network exchanges as the foundation for fostering innovation in education and teaching, creating a professional development community focused on constructive and innovative education and teaching research.

2.2. Mechanism of investment efficiency

The ESG evaluation system fulfills a dual purpose by both placing restrictions on businesses and offering data and tools to promote corporate investment. A higher ESG score typically denotes better business success and a closer bond between the company and its stakeholders. As a result, stakeholders are more inclined to share knowledge and resources with the organization. The ESG score also places restrictions on businesses, forcing them to increase their green spending in order to uphold their good reputation and meet public and regulatory expectations. Therefore, through resource support and investment limits, ESG improves the effectiveness of enterprises' investments. Higher levels of investment efficiency result in lower levels of inefficient investment, investments that are closer to being optimal, higher rates of resource utilization, and higher levels of innovation output, including green innovation. In other words, companies with better ESG scores are predicted to exhibit more effective investment strategies and produce more green innovation. This justification leads us to suggest the subsequent research project:

(H2) ESG promotes corporate green innovation by fostering investment efficiency.

2.3. Mechanism of government-business relations

Stronger ties between a corporation and its stakeholders are related to higher ESG scores. Companies in China give their connection with the government a lot of consideration. A good relationship with the government has several advantages, including tax breaks, subsidies, and streamlined procedures for manufacturing and management. Additionally, the local biological environment is directly impacted by the conduct of the local administration. As a result, businesses with stronger ESG performance are more likely to get government support, while those with worse performance may be subject to restrictions. Given the long-term risks associated with green innovation, businesses may be hesitant to launch green innovation projects. However, businesses with good ties to the government may receive more government funding, which helps spread out the risks and losses connected to innovation[34]. As a result, firms are encouraged to actively participate in green innovation efforts. Finally, higher ESG scores strengthen the business-government relationship, provide more money for green innovation, and ultimately drive innovation. As a result, we propose the following research topic:

(H3) ESG rankings encourage corporate green innovation through enhancing government-business interactions.

2.4. Moderation effect of green and black attributes

The ESG evaluation is essential to the green financial system because it resolves environmental externalities and encourages the effective distribution of financial resources through the flow of green funds. This grading system has a specific impact on how small - and medium-sized businesses get financed. The micro-level green effects of the ESG system are significantly influenced by environmental factors, both internal and external. Companies may engage in greenwashing practices to cover up their subpar environmental performance when they have stronger black characteristics, which are characterized by environmental information asymmetry and increased environmental dangers. This can result in the preservation of exaggerated ESG scores. To stop such greenwashing activities and lessen the impact of the ESG system, external rules are required. On the other hand, there is less environmental information asymmetry and reduced environmental risks when businesses exhibit higher green characteristics. This maximizes the micro-level green effects of the ESG system by allowing ESG scores to more properly and objectively reflect the firms' ESG performance. In conclusion, we suggest the pursuing research hypotheses:

(H4) While green features strengthen the promotion effect of ESG scores on business green innovation, black attributes lessen the beneficial impact of ESG scores on the green innovation of firms.

3. Methodology

3.1. Sample and Data

The research sample utilized in this study comprises Chinese-listed companies in the Shanghai and Shenzhen A-shares markets, spanning the period from 2010 to 2019. Several treatments were applied to the sample, including the exclusion of financial sector companies, ST (Special Treatment), PT (Protection Treatment), and *ST (Special Treatment) companies, as well as companies listed before 2010 and samples with missing essential characteristics. After the processing steps, a total of 8, 258 annual observations were collected from 1, 090 listed companies. To ensure data reliability, primary variables underwent Winsorization, removing values at the extreme 1% and 99% tails.

To gather the necessary data for our analysis, we employed multiple reputable sources. Green patent data was obtained from the China Research Data Service Platform (CNRDS), a widely recognized and authoritative database in the field. To ensure comprehensive financial information, we utilized corporate financial data from the CSMAR and Wind databases, renowned repositories of financial data that are widely utilized in academic research. Hexun. com social responsibility reports, a reputable platform for corporate social responsibility information, provided valuable data on environmental disclosure and other relevant factors. To assess corporate ESG performance, we relied on Bloomberg' s Corporate Social Responsibility Disclosure Index, specifically utilizing the Bloomberg ESG Disclosure Scores. These scores provide a comprehensive assessment of ESG performance across various dimensions. Finally, to capture regional environmental and economic factors, we sourced data from reputable providers specializing in regional data, ensuring accuracy and reliability in our analysis.

These comprehensive data sources enable a robust analysis of the impact of ESG on corporate green innovation performance, allowing for a detailed examination of the relationship between ESG factors and green innovation outcomes in the Chinese context. In addition, it is clear from an examination of the pertinent literature that the majority of scholars situate the theoretical underpinnings of the "Master Teacher Studio" within the context of a professional learning community, with a focus on the particular situation in China. These studios stand for a shared vision and frequent social contacts.

3. 2. Variables

3. 2. 1. Explained variable

We take into account both quantitative and qualitative factors as we operationalize the green innovation success of businesses. To create two explanatory variables, we specifically calculate the logarithmic sums of the distributions for the number of green inventions (GI) and green patent citations (GC).

3. 2. 2. Explanatory variable

The ESG data utilized in this study were sourced from the Bloomberg ESG Disclosure Scores, a comprehensive dataset consisting of 122 sub-scores encompassing 21 subjects across three primary categories: environmental, social, and governance. This dataset provides a detailed assessment of companies' ESG performance, enabling a thorough analysis of their environmental, social, and governance practices. By incorporating a wide range of sub-scores and covering multiple dimensions within each category, the Bloomberg ESG Disclosure Scores offer extensive and nuanced information on the ESG performance of the included companies.

3. 2. 3. Intermediary variables

3. 2. 3. 1. Efficacy of investments comes first (IE)

We employ the absolute value of the residuals obtained from the subsequent regression, following model (1)[66], as a measure of inefficient investment. A higher value of this indicator indicates lower efficiency in the firm' s investment activities.

$$CI_{i,t} = \beta_0 + \beta_1 SG_{i,t-1} + \varepsilon_{i,t} \quad (1)$$

In model (1), the variable $CI_{i,t}$ represents the investment level of a firm, measured as the ratio of fixed assets and intangible assets to total assets. The variable $ESG_{i,t}$ denotes the investment opportunity of the firm, which is evaluated based on the growth rate of sales revenue. The residual term captures the portion of the investment that is inefficient, and to quantify this, we calculate the investment efficiency index

(IE) by taking the absolute value of the residual. A higher value of the index indicates lower investment efficiency, implying that a larger proportion of the firm's investment is considered inefficient. This model allows us to examine the relationship between investment level, investment opportunity, and investment efficiency, and their impact on the firm's overall performance.

3. 2. 3. 2. Government subsidies (Subsidy)

To capture the dynamics of the government-enterprise relationship, we utilize the normalized government subsidy (Subsidy) as a proxy variable. This variable serves as an indicator of the strength of the relationship between the firm and the government within our sample. A higher value of the Subsidy variable signifies a more pronounced government-enterprise relationship, as it suggests that the firm has received a greater amount of government subsidies. By incorporating this variable into our analysis, we aim to examine the impact of the government's support on the firm's performance and its engagement in green innovation activities.

3. 2. 4. Control variables

Our study includes a comprehensive set of control variables, following a similar approach to prior research[4, 15, 55, 67]. These variables encompass various characteristics of the firms under investigation, including their age (measured by the year of foundation), gearing (leverage), return on total assets (ROA), Tobin's Q, net cash from investing activities (ICF), fixed assets (fix), foreign ownership (QFII), dual employment (Dual), and audit opinion (Opinion). By including these control variables in our analysis, we aim to account for potential confounding factors and enhance the robustness of our empirical findings. Table 1 provides a comprehensive overview of the key factors considered in our empirical analysis.

Table 1 Descriptive statistics of the variables

Variable classification	Variable name	Variable symbol	Variable definition
Explained variables	Quantity of Green Innovation	GI_{t+1}	The logarithm of the number of green patent applications plus one to take the logarithm
	Quality of Green Innovation	GCI_{t+1}	The logarithm of the number of green patent citations plus one to take the logarithm
Core explanatory variables	ESG Score	ESG	Logarithm of Bloomberg ESG
Intermediate variables	Investment efficiency	IE	Estimated from the model (1)
	Government Grants	Subsidy	Normalized government grants
Control variables	Years of Establishment	Age	Ln(year − year of establishment)
	Gearing Ratio	Leverage	Total liabilities/total assets
	Total Return on Assets	ROA	Total profit/total assets
	Tobin's Q	Q	Total market capitalization/total assets
	Net cash from investing activities	ICF	Net cash from investing activities/total assets
	Fixed Assets	Fix	Fixed Assets/Total Assets
	Foreign equity holdings	QFII	Foreign shareholding ratio
	Two positions in one	Dual	The value is 1 if the chairman is also the general manager, otherwise, it is 0
	Audit opinion	Opinion	The standard unqualified opinion takes the value of 1, otherwise, it is 0

3. 3. Model

3. 3. 1. Baseline model

The following econometric model was created for empirical testing to test hypothesis H1 based on the preceding analysis and variable definitions.

$$GI_{i,t+1} = \alpha_0 + \alpha_1 ESG_{i,t} + \gamma X_{i,t} + \lambda_t + \eta_j + \varepsilon_{i,t} \quad (2)$$

The variable $ESG_{i,t}$ represents the Bloomberg ESG score of firm i in year t, whereas $GI_{i,t+1}$ indicates the level of green innovation exhibited by firm i in the subsequent year, t+1. To account for various factors that may influence the relationship between ESG scores and green innovation, we introduce a set of control variables denoted by the notation $X_{i,t}$. Here, t denotes time-fixed effects, which capture time-specific factors that may affect both ESG scores and green innovation. The inclusion of industry-fixed effects, denoted by j, allows us to account for industry-specific characteristics and dynamics that may influence the relationship of interest. Furthermore, the random disturbance term, represented by i, t, encompasses unobserved factors that could impact the relationship between ESG scores and green innovation, ensuring robustness in our analysis. By incorporating these control variables, we aim to provide a comprehensive understanding of the relationship between ESG scores and green innovation, while simultaneously addressing potential confounding factors and endogeneity concerns.

3. 3. 2. Intermediation model

To evaluate the mediating effects of investment efficiency (IE) and the connection between the government and the enterprise (Subsidy) relative to H2 and H3, this study constructs a mediation model and goes through the following testing steps. If coefficient 1 in the regression model (1), which depicts the strong correlation between corporate green innovation and ESG score, is statistically significant, the investigation proceeds to the next stage. A regression equation is then created to determine how the mediating factors (IE and Subsidy) and corporate green innovation are affected by the ESG score. If coefficient μ2 is significant and shares the same sign as β1, it indicates the presence of a mediating mechanism.

$$IE_{i,t}/Subsidy_{i,t} = \beta_0 + \beta_1 ESG_{i,t} + \gamma X_{i,t} + \lambda_t + \eta_j + \varepsilon_{i,t} \quad (3)$$

$$GI_{i,t+1} = \mu_0 + \mu_1 ESG_{i,t} + \mu_2 IE_{i,t}/Subsidy_{i,t} + \gamma X_{i,t} + \lambda_t + \eta_j + \varepsilon_{i,t} \quad (4)$$

where $IE_{i,t}$ and $Subsidy_{i,t}$ are investment efficiency and government subsidies, respectively, while the remaining variables are consistent with the baseline model.

3. 3. 3. Moderating effect model

Based on the baseline model, the following regression model was created to assess H4, the moderating influence of firm environmental variables.

$$GI_{i,t+1} = \alpha_0 + \alpha_1 ESG_{i,t} + \alpha_2 ESG_{i,t} \times R_{it} + \gamma X_{i,t} + \lambda_t + \eta_j + \varepsilon_{i,t} \quad (5)$$

The variable R in our analysis encompasses both black and green corporate characteristics. Black pollution features encompass regional, industrial, and corporate aspects. To capture these characteristics, we employ several dummy variables. The high pollution region dummy variable (HPR) takes a value of 1 if the regional pollution index for the current year exceeds the average value, and 0 otherwise. Similarly, the high pollution industry dummy variable (HPI) is assigned a value of 1 if the industry is classified as high pollution, and 0 otherwise. The high pollution company dummy variable (HPC) assigns a value of 1 to firms considered crucial for pollution monitoring and 0 otherwise.

In contrast, green characteristics encompass environmental considerations at the company, city, and provincial levels. To capture these green aspects, we incorporate the provincial green finance variable

(DGF), which represents the normalized green finance index. Furthermore, we examine the degree of green innovation (DGI) at the city level, calculated by dividing the total number of green patents by the average number of patents in the city during the current year. Additionally, we introduce the corporate environmental disclosure variable, which quantifies the proportion of quantitative disclosures related to environmental liability items relative to the total number of disclosed items. By incorporating these variables, we aim to capture the multifaceted nature of green characteristics and their potential influence on the relationship between ESG scores and green innovation.

The remaining variables in our analysis support model (2), which examines the relationship between ESG ratings and corporate green innovation performance.

3. 4. Descriptive statistics

Table 2 provides the descriptive statistics for the key variables in our analysis. The variable representing green patents (GI) exhibits a mean value of 0. 25, with a standard deviation of 0. 62. The range of values spans from the lowest possible value of 0 to the highest value of 0. 48. These statistics indicate a substantial variation in the level of green innovation among the firms included in the sample, with an overall low average level of green innovation observed. The descriptive statistics for ESG ratings demonstrate significant variability. The mean value of ESG ratings is 2. 97, with a standard deviation of 0. 31. The range of scores ranges from the lowest score of 2. 21 to the highest score of 3. 77. The median value for ESG scores is 2. 99. These statistics highlight the diverse nature of ESG scores across the sample, indicating variations in the environmental, social, and governance performance of the included businesses. Overall, these descriptive statistics provide valuable insights into the distribution and range of green patents and ESG ratings among the firms in the study. Understanding these variations is essential for comprehending the diversity in green innovation capabilities and ESG performance among the analyzed businesses.

Table 2 Descriptive statistics of the main variables

Variables	N	Mean	S. D.	Max	Median	Min
GIt+1	8258	0. 25	0. 62	2. 48	0. 00	0. 00
GCt+1	8258	0. 41	0. 92	4. 56	0. 00	0. 00
ESG	8258	2. 97	0. 31	3. 77	2. 99	2. 21
Age	8258	2. 87	0. 32	3. 53	2. 89	1. 61
Leverage	8258	0. 47	0. 20	0. 89	0. 48	0. 05
ROA	8258	7. 29	6. 17	36. 44	5. 95	−8. 26
Q	8258	1. 90	1. 24	8. 78	1. 48	0. 88
ICF	8258	−0. 06	0. 08	0. 17	−0. 05	−0. 39
Fix	8258	0. 23	0. 18	0. 70	0. 19	0. 00
QFII	8258	0. 17	0. 54	2. 79	0. 00	0. 00
Dual	8258	0. 20	0. 40	1. 00	0. 00	0. 00
Opinion	8258	0. 99	0. 12	1. 00	1. 00	0. 00

3. 5. Correlation test

The correlation coefficient test matrix, shown in Table 3, sheds light on the relationship between ESG scores and corporate green innovation. According to the findings in Table 3, there is a substantial positive correlation between ESG scores and corporate green innovation. This data provides preliminary support for hypothesis H1.

Table 3 Pearson correlation coefficient test

	GIt+1	GIt+2	GIt+3	GCt+1	GC+2	GCt+3	ESG
GIt+1	1.000						
GIt+2	0.710***	1.000					
GIt+3	0.567***	0.700***	1.000				
GCt+1	0.513***	0.460***	0.408***	1.000			
GCt+2	0.608***	0.509***	0.456***	0.918***	1.000		
GCt+3	0.689***	0.605***	0.502***	0.892***	0.923***	1.000	
ESG	0.118***	0.102***	0.103***	0.200***	0.188***	0.172***	1.000

Note: *** $P<0.01$; ** $P<0.05$; * $P<0.1$.

4. Empirical results and analysis

4.1. Baseline regression

The regression findings for the ESG benchmark are presented in Table 4. In columns (1) through (3), the coefficients of ESG on the number of green innovation patents reported by firms in periods t+1, t+2, and t+3 are estimated to be 0.329, 0.313, and 0.317, respectively. These coefficients exhibit statistical significance at the 1% level, providing evidence that ESG has a positive impact on the quantity of green innovation patent applications made by businesses. Furthermore, based on columns (1) through (3), the regression coefficients of ESG on the number of green innovation patents cited by firms in periods t+1, t+2, and t+3 are estimated to be 0.609, 0.622, and 0.613, respectively. These coefficients also demonstrate statistical significance, suggesting that ESG promotes the citation of patents related to green innovation. The regression results consistently support the hypothesis that ESG performance is associated with higher levels of both reported and cited green innovation patents. These findings contribute to our understanding of the positive relationship between ESG and green innovation outcomes, providing valuable insights for businesses, policymakers, and researchers. These regression results provide empirical support for hypothesis H1, as both the quantity and quality of green innovation output increase with higher ESG scores. The descriptive statistics for the remaining control variables generally align with previous studies[35, 55, 58].

4.2. Intermediary Mechanism Analysis

4.2.1. Mechanism of investment efficiency

The regression results, specifically in columns (1) to (3) of Table 5, shed light on the mediating role of investment efficiency. The findings reveal a significant positive relationship between ESG scores and investment efficiency, as indicated by the coefficient estimate of −3.183 for ESG in column (1) at the 1% significance level. This implies that companies with higher ESG scores tend to exhibit superior investment efficiency. Moreover, the coefficient estimates for IEt+1 in columns (2) and (3), which are −0.003 and −0.005 respectively, exhibit a statistically significant negative relationship at the 5% significance level. These results suggest a potential mediating effect, emphasizing the crucial link between effective investment strategies and the success of green innovation initiatives. Furthermore, both coefficient estimates for ESG in columns (2) and (3), namely 0.291 and 0.594 respectively, are highly positive and statistically significant at the 1% significance level. This highlights the positive influence of ESG performance on the efficacy of green innovation. These findings provide support for hypothesis H3, indicating that firms' investment efficiency is enhanced through their ESG performance. Overall, the regression results demonstrate that investment efficiency plays a mediating role in the relationship between ESG and green innovation. The significant positive effect of ESG on investment efficiency further reinforces the positive impact of ESG on green innovation outcomes. These findings contribute to a better understanding of the mechanisms through

which ESG performance influences firms' green innovation initiatives. Overall, our regression results provide evidence that ESG performance positively influences enterprises' investment efficiency, which, in turn, contributes to their superior performance in terms of green innovation.

Table 4 Baseline regression results

	(1)	(2)	(3)	(4)	(5)	(6)
	GIt+1	GIt+2	GIt+3	GCt+1	GCt+2	GCt+3
ESG	0.300***	0.286***	0.299***	0.609***	0.622***	0.613***
	(7.07)	(6.82)	(7.21)	(7.33)	(6.61)	(6.25)
Age	−0.185**	−0.160*	−0.144*	−0.211	−0.206	−0.184
	(−1.99)	(−1.73)	(−1.66)	(−1.26)	(−1.13)	(−0.96)
Leverage	0.180**	0.171**	0.185**	0.329**	0.371**	0.387**
	(2.33)	(2.00)	(2.26)	(2.15)	(2.12)	(2.03)
ROA	0.002	0.002	0.002	−0.006*	−0.004	−0.002
	(0.82)	(0.70)	(0.79)	(−1.85)	(−0.95)	(−0.40)
Q	−0.026**	−0.026**	−0.014	0.010	0.011	0.011
	(−2.37)	(−2.13)	(−1.18)	(0.62)	(0.52)	(0.48)
ICF	−0.067	−0.070	−0.106	−0.417*	−0.327	−0.293
	(−0.56)	(−0.59)	(−0.76)	(−1.89)	(−1.34)	(−1.15)
Fix	−0.033	−0.034	−0.050	−0.386***	−0.416**	−0.439**
	(−0.25)	(−0.25)	(−0.37)	(−2.72)	(−2.59)	(−2.44)
QFII	0.026	0.028	0.020	0.032	0.035	0.043
	(0.85)	(0.90)	(0.67)	(0.75)	(0.70)	(0.73)
Dual	0.041	0.052	0.062	0.097	0.117	0.147
	(1.17)	(1.38)	(1.54)	(1.28)	(1.37)	(1.57)
Opinion	0.082*	0.131*	0.109	−0.123	−0.099	0.106
	(1.82)	(1.92)	(1.60)	(−1.17)	(−0.72)	(0.67)
Constant	−0.148	−0.196	−0.247	−0.737	−0.804	−1.004
	(−0.46)	(−0.66)	(−0.85)	(−1.32)	(−1.34)	(−1.52)
Y/I/P FE	YES	YES	YES	YES	YES	YES
Observations	8,258	7,017	5,850	8,258	6,891	5,627
Adj R2	0.113	0.115	0.120	0.0990	0.0950	0.0883

Note: T-statistics calculated for city-level clusters in parentheses. *** $P<0.01$; ** $P<0.05$; * $P<0.1$.

Table 5 Regression results for mediating mechanisms

	(1)	(2)	(3)	(4)	(5)	(6)
	IEt+1	GIt+1	GCt+1	Subsidy	GIt+1	GCt+1
ESG	−3.184***	0.291***	0.594***	0.027***	0.239***	0.465***
	(−4.65)	(7.16)	(7.33)	(3.23)	(5.14)	(5.50)
IEt+1		−0.003**	−0.005**			
		(−2.53)	(−2.38)			
Subsidy					2.289***	5.407***
					(10.80)	(7.58)
Constant	13.907***	−0.109	−0.673	−0.036*	−0.065	−0.541
	(3.50)	(−0.34)	(−1.25)	(−1.69)	(−0.21)	(−1.04)
Controls	YES	YES	YES	YES	YES	YES
Y/I/P FE	YES	YES	YES	YES	YES	YES
Observations	8,258	8,258	8,258	8,258	8,258	8,258
Adj R2	0.0820	0.139	0.163	0.252	0.115	0.101

Note: *** $P<0.01$; ** $P<0.05$; * $P<0.1$.

4. 2. 2. Mechanism of government-business relations

The results of the mediating effect of the government-firm relationship are presented in columns (4) to (6) of Table 5. It is worth noting that higher ESG ratings have a significant positive effect on the government's support for the company, as evidenced by the coefficient estimate for ESG in column (4), which is 0. 027. This coefficient estimate is highly significant at the 1% level, indicating that ESG ratings play a crucial role in strengthening the relationship between the company and the government. Moreover, both coefficient estimates for the variable Subsidy in columns (5) and (6) are positive at the 1% level, with values of 0. 228 9 and 5. 407, respectively. These findings suggest that government subsidies contribute to the advancement of green technology. Consequently, enhanced government relations facilitate an increase in government subsidies allocated to businesses, providing them with additional financial resources for investment in green innovation initiatives. These results support the presence of a mediating effect. However, it is important to note that the coefficient values for the Subsidy variable in this mediating model are lower than those observed in the baseline regression. This indicates a partial mediation effect, suggesting that the influence of ESG on green innovation is partially mediated by the government-firm relationship and subsequent government subsidies. Nevertheless, the regression results demonstrate that ESG performance enhances corporate green innovation by strengthening the bond between the government and the firm. This finding is consistent with our hypothesis H2, which posits that ESG plays a pivotal role in fostering green innovation through improved government relations.

4. 3. Moderation effects analysis

When comparing the estimated values of the baseline regression for ESG, we observe a decline in both the significance and coefficient values of the interaction terms between ESG and variables related to negative characteristics (HPR, HPI, and HPC), as indicated in the Black Features of Table 6. This decline suggests that the positive effect of ESG on green innovation diminishes when firms possess stronger negative characteristics. In contrast, the regression results in Green Features reveal that the coefficients of ESG interacting with variables related to positive green characteristics (DGF, CGI, and EDG) are all statistically significant at the 1% level and higher than the coefficients observed in the baseline regression. These findings indicate that the positive influence of ESG on green innovation is strengthened when firms exhibit stronger green characteristics, such as a higher provincial green finance index (DGF), a greater degree of green innovation (CGI), and a higher proportion of environmental disclosure (EDG). These results emphasize the nuanced nature of the relationship between ESG and green innovation. While the interaction with negative characteristics weakens the positive effect, the interaction with positive green characteristics strengthens it. This highlights the importance of considering the contextual factors that influence the relationship between ESG and green innovation outcomes. These findings contribute to a better understanding of the complex dynamics involved in the interaction between ESG and green innovation, shedding light on the factors that enhance or diminish the impact of ESG on firms' green innovation performance. This shows that the favorable influence of ESG on green innovation grows as the green qualities of businesses become stronger.

5. Robustness tests

5. 1. Replacing measures of core variables

In order to further investigate the effects of different components of ESG evaluation, we replaced the variable ESG with the natural logarithm of the corresponding ratings for Environmental (E), Social (S),

and Corporate Governance (G). Additionally, we replaced the variables GIt+1 and GCt+1 with GCIt+1 to focus specifically on patents related to green inventions. The regression results for these variable replacements are presented in Table 7. In columns (1) to (3), the coefficient estimates for G are higher compared to those for E, while the estimates for S and E are significantly positive at the 1% level. However, the coefficient estimates for G are not statistically significant. Conversely, the coefficient estimates for E, S, and G are all substantially positive at the 1% level in columns (1) to (3), with their values increasing in the order of G, S, and E. This indicates that the order of G, S, and E determines the favorable effects on the quality of green patents. Furthermore, in column (7), the coefficient estimate for ESG is 0.265 and significant at the 1% level. Notably, this coefficient value is lower than the coefficient estimate obtained from the main regression, which is 0.300. This suggests that while ESG has a significant impact on overall green patents, its influence on patents specifically related to green inventions may be comparatively weaker. The findings from these regressions provide insights into the varying effects of different components of ESG evaluation on the quality and overall quantity of green patents. By considering the individual components of E, S, and G, we gain a more nuanced understanding of their contributions to green innovation outcomes. These findings shed light on the varying impacts of different components of the ESG evaluation on the quality of green patents, highlighting the significance of considering the specific components of E, S, and G individually.

Table 6 Regression results for the moderating effects of black and green attributes

	(1)	(2)	(3)	(4)	(5)	(6)
	GIt+1	GCt+1	GIt+1	GCt+1	GIt+1	GCt+1
Black Features						
ESG×HPP	0.026	0.101**				
	(1.40)	(2.54)				
ESG×HPI			0.015*	0.038**		
			(1.78)	(2.24)		
ESG×HPC					0.011	0.067***
					(1.43)	(4.14)
Constant	0.693**	0.977**	0.677**	0.930*	0.698**	1.024**
	(2.40)	(1.99)	(2.31)	(1.86)	(2.38)	(2.05)
Controls	YES	YES	YES	YES	YES	YES
Y/I/P FE	YES	YES	YES	YES	YES	YES
Observations	8,258	8,258	8,258	8,258	8,258	8,258
Adj R2	0.0954	0.0684	0.0960	0.0683	0.0953	0.0719
Green Features						
ESG×DGF	0.386***	0.826***				
	(3.99)	(3.83)				
ESG×CGI			0.572*	1.306**		
			(1.93)	(2.48)		
ESG×EDG					0.856***	1.360***
					(4.80)	(4.31)
Constant	−0.469*	−1.521***	0.820**	1.042**	0.673**	0.933*
	(−1.66)	(−2.64)	(2.58)	(2.13)	(2.34)	(1.91)
Controls	YES	YES	YES	YES	YES	YES
Y/I/P FE	YES	YES	YES	YES	YES	YES
Observations	8,258	8,258	5,439	5,439	8,258	8,258
Adj R2	0.104	0.0832	0.127	0.125	0.0996	0.0706

Note: *** $P<0.01$; ** $P<0.05$; * $P<0.1$.

Table 7 Regression results for replacing core variables

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	GIt+1	GIt+1	GIt+1	GCt+1	GCt+1	GCt+1	GCIt+1
E	0.121***			0.265***			
	(6.75)			(6.95)			
S		0.158***			0.305***		
		(5.68)			(6.33)		
G			0.257			0.747**	
			(1.55)			(2.02)	
ESG							0.265***
							(5.47)
Constant	0.484	0.244	−0.262	0.356	0.054	−1.804	−0.158
	(1.58)	(0.76)	(−0.33)	(0.64)	(0.10)	(−1.10)	(−0.46)
Controls	YES	YES	YES	YES	YES	YES	YES
Y/I/P FE	YES	YES	YES	YES	YES	YES	YES
Observations	6,950	8,035	8,258	6,950	8,035	8,258	8,258
Adj R2	0.120	0.107	0.0969	0.0999	0.0821	0.0725	0.0739

Note: *** $P<0.01$; ** $P<0.05$; * $P<0.1$.

5.2. Placebo test

To assess the robustness of our baseline regression analysis, we conducted a non-parametric permutation test, specifically a placebo test. The results of this test are visually illustrated in Figure 1. By generating 500 random samples, we observed that the distribution of projected coefficients closely approximated a normal distribution centered around zero. Importantly, we observed notable disparities between the correlation coefficients obtained from the non-parametric tests and the benchmark regression coefficients for the green innovation variables GIt+1 and GCt+1. These disparities are visually represented by the dashed lines in Figure 1, corresponding to the coefficients reported in Table 4, specifically columns (3) and (6). The findings from the placebo test provide further evidence regarding the robustness of our baseline regression analysis. The close alignment of the distribution of the projected coefficients with a normal distribution centered around zero reinforces the validity of our results. Moreover, the clear disparities between the correlation coefficients derived from the non-parametric tests and the benchmark regression coefficients for the green innovation variables highlight the distinct and significant impact of these variables on the study outcomes. This strengthens the reliability and credibility of our regression results and underscores the significance of the relationship between ESG and green innovation. This implies that the observed effect of ESG on green innovation performance is not attributable to other unobservable factors. The findings from the placebo test provide further support for the stability and reliability of the baseline regression results, reinforcing the notion that the relationship between ESG and green innovation is statistically significant and not spurious. In other words, the placebo test results exclude the possibility of interference from other events in the benchmark regression, supporting the robustness of the obtained benchmark regression results.

5.3. Adding variables

In order to enhance the robustness and validity of the baseline regression results, we introduce additional federal and provincial control variables that could potentially influence firm-level green innovation. We augment the initial regression in column (1) by including the following variables: (i) Regional per capita gross product (PerGDP): This variable captures the logarithm of the regional per capita gross product, serving as a measure of economic development and prosperity within the region; (ii) Regional financial

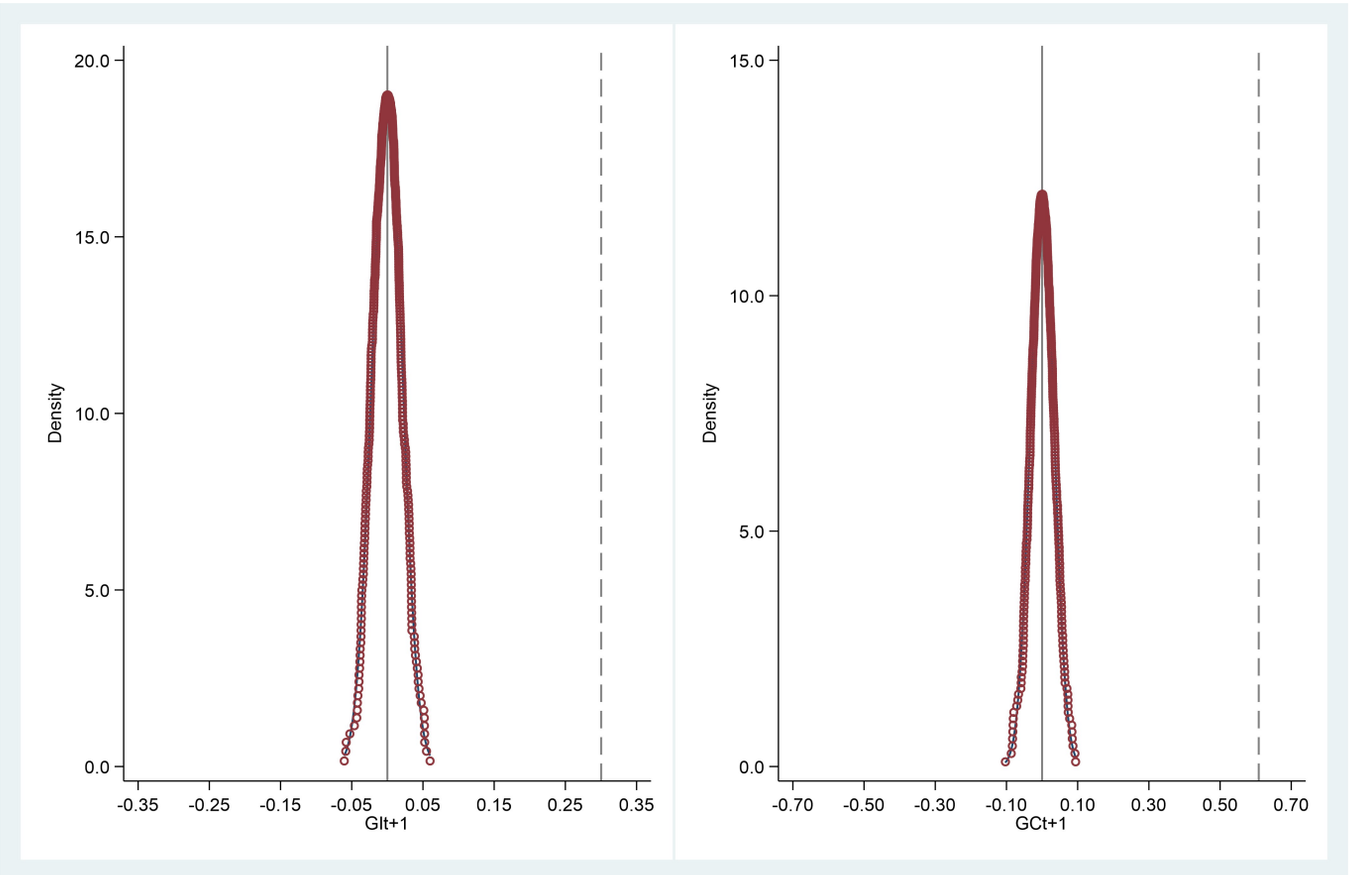

Figure 1. Placebo test

development level (FD): This variable represents the share of regional deposit and loan activities in relation to the gross national product (GNP), reflecting the level of financial development in the region; (iii) Regional pollution level (DPG): This variable measures the extent of industrial pollution investment as a proportion of the GNP, providing insights into the regional pollution level; (iv) Broad money growth rate (M2): This variable denotes the rate of growth in broad money supply, reflecting the monetary policy conditions and liquidity in the economy; and (v) Shanghai interbank lending rate: This variable captures the prevailing interest rate for interbank lending in the Shanghai market, serving as a proxy for the cost of borrowing and the overall financial market conditions. By incorporating these additional federal and provincial control variables, we aim to account for potential confounding factors and further examine the relationship between ESG and firm-level green innovation, ensuring the robustness and reliability of the regression findings. These control variables account for the macroeconomic, environmental, and regional economic influences on the benchmark regressions. The results of the regressions with these additional control factors are shown in Table 8. It is noteworthy that all of the coefficient estimations for ESG are significantly positive at the 1% level. The regression results, which demonstrate overall concordance with the benchmark regression, provide additional evidence for the reliability of our findings. While accounting for the effects of regional economic, environmental, and macroeconomic factors, these results further establish the link between ESG and enterprises' green innovation.

5. 4. Replacement regression models

Poisson, Tobit, and Negative Binomial regression models can all be used to evaluate the data because the variables GIt+1 and GCt+1 are discrete. Table 9 presents the results of the substitution regression model. The results of the regression show that all of the ESG coefficient estimations are significantly positive at the

1% level. These results are consistent with the results of the initial regression, illustrating the resilience and consistency of our findings across several regression models.

Table 8 Regression results for adding control variables

	(1)	(2)	(3)	(4)
	GIt+1	GIt+1	GCt+1	GCt+1
ESG	0.301***	0.301***	0.609***	0.609***
	(7.10)	(7.10)	(7.33)	(7.33)
FD	0.002	0.002	−0.002	−0.002
	(1.07)	(1.07)	(−1.21)	(−1.21)
DPG	−0.208**	−0.208**	0.089	0.089
	(−2.56)	(−2.56)	(0.59)	(0.59)
M2		0.288***		−0.142*
		(5.05)		(−1.72)
Shibor		1.043***		−0.476
		(4.90)		(−1.55)
Constant	−5.300***	−10.082***	−0.341	1.829
	(−2.73)	(−3.48)	(−0.13)	(0.46)
Controls	YES	YES	YES	YES
Y/I/P FE	YES	YES	YES	YES
Observations	8, 258	8, 258	8, 258	8, 258
Adj R2	0.114	0.114	0.0743	0.0743

Note: *** $P<0.01$; ** $P<0.05$; * $P<0.1$.

Table 9 Regression results of the replacement model

	(1)	(2)	(3)	(4)	(5)	(6)
	Poisson	Tobit	NB	Poisson	Tobit	NB
	GIt+1	GIt+1	GIt+1	GCt+1	GCt+1	GCt+1
ESG	1.181***	0.300***	1.169***	1.376***	0.609***	1.378***
	(8.24)	(7.10)	(7.35)	(9.37)	(7.36)	(8.08)
Constant	−4.124***	−0.148	−3.901***	−4.029***	−0.737	−3.857***
	(−3.71)	(−0.46)	(−3.41)	(−3.72)	(−1.33)	(−3.43)
Controls	YES	YES	YES	YES	YES	YES
Y/I/P FE	YES	YES	YES	YES	YES	YES
Observations	8, 258	8, 258	8, 258	8, 258	8, 258	8, 258
Loglikelihood	−4437	−7176	−4338	−6926	−10599	−6345
Pseudo R2	0.186	0.0684	0.147	0.118	0.0416	0.0674

Note: *** $P<0.01$; ** $P<0.05$; * $P<0.1$.

5.5. Instrumental variables approach

To address potential simultaneity bias and reverse causality issues, we use green innovation indicators for period t + 1, which helps reduce estimation errors associated with these problems. Although still endogenous, the relationship between ESG and green innovation suggests that businesses that do better in terms of green innovation may also perform better in terms of ESG. Additionally, there can be omitted elements that have an impact on ESG ratings. These factors raise the issue of endogeneity by having the ability to introduce bias and inconsistent results into the benchmark regressions.

To address the endogeneity issue, we employ instrumental variables in our analysis. In this study, we utilize the industry-level ESG mean (ESGMeant − 1) from the previous year as the instrumental variable[68]. The choice of this instrumental variable is based on the rationale that while the industry may

influence the ESG score, the industry mean does not have a direct correlation with the specific environmental performance of individual companies. Hence, it satisfies the criteria for an instrumental variable. Before proceeding with the instrumental variable-ordinary least squares regression, we conduct an ESGMeant-1-ESG correlation coefficient test. The purpose of this test is to assess the correlation between ESG performance and the industry ESG means. The test results indicate a significant positive correlation coefficient of 0.194 at the 1% level. Based on this preliminary finding, we conclude that firms' ESG performance is positively correlated with higher industry ESG means. By incorporating instrumental variables and conducting the necessary tests, we address potential endogeneity concerns and strengthen the internal validity of our regression analysis. This approach allows us to obtain reliable estimates of the causal relationship between ESG performance and firm-level green innovation.

Table 10 presents the results of the two-stage least squares (2SLS) regression analysis incorporating instrumental variables. The coefficient estimates obtained from the first stage of the regression indicate that ESGMeant-1 has a statistically significant positive effect at the 1% level, with coefficients of 0.929 and 0.679, respectively. This finding suggests that the industry in which a firm operates influences its ESG performance, confirming the impact of industry-level factors on ESG scores. Furthermore, the second stage regression reveals the estimated coefficients for ESG, which are highly significant at the 1% level. These coefficients demonstrate a favorable impact of ESG on business performance in terms of green innovation. The results from the 2SLS regression analysis, supported by the significant coefficients from the first and second stages, provide empirical evidence of the positive relationship between ESG and firm-level green innovation. By accounting for potential endogeneity issues through the use of instrumental variables, we establish a more robust and reliable estimation framework, enhancing the credibility of our findings. These results contribute to a deeper understanding of the role of ESG in driving green innovation within businesses.

Table 10 Least squares regression results for instrumental variables

	(1)	(2)	(3)	(4)	(5)	(6)
	ESG	ESG	GIt+1	GIt+1	GCt+1	GCt+1
ESGMeant-1	0.929***	0.679***				
	(24.83)	(17.29)				
ESG			0.727***	0.757***	0.785***	1.156***
			(9.83)	(6.89)	(6.51)	(6.56)
Constant	2.917***	2.766***	-1.719***	-1.419***	-1.801***	-2.260***
	(121.77)	(54.35)	(-7.95)	(-4.45)	(-5.16)	(-4.45)
Observations	8,258	8,258	8,258	8,258	8,258	8,258
Controls	Controls	Controls	Controls	Controls	Controls	Controls
Y/I/P FE	Controls	YES	YES	YES	YES	YES
Adj R2	0.174	0.211	0.0661	0.0707	0.0788	0.0718
F statistics	36.70	35.95	23.10	19.64	15.98	12.26
P value	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]
Kleibergen-Paap rk LM statistic			416.915	235.653	416.915	235.653
P value			[0.0000]	[0.0000]	[0.0000]	[0.0000]
Cragg-Donald Wald F statistic			528.820	262.190	528.820	262.190
Kleibergen-Paap rk Wald F statistic			616.709	299.097	616.709	299.097

Note: *** $P<0.01$; ** $P<0.05$; * $P<0.1$.

Following the main regression analysis, we conducted several tests on the instrumental variables employed in the study. These tests aimed to assess the exogeneity of the instrumental factors, the presence

of weak instruments, and potential issues of over-identification. The results of these tests indicate that our model successfully passes each test, thereby providing confidence in the reliability and validity of our conclusions. The tests for exogeneity demonstrate that the instrumental variables used in the analysis are not affected by endogeneity issues, suggesting that they are suitable for addressing potential endogeneity concerns in the regression model. Additionally, the tests for weak instruments indicate that the instrumental variables possess sufficient strength to effectively capture the variation in the endogenous variable of interest. Moreover, the tests for over-identification reveal that the instruments used in the model do not suffer from excessive instrument count or redundancy, ensuring the robustness of our instrumental variable estimation. The satisfactory performance of these tests enhances the credibility of our findings and strengthens the overall validity of our conclusions. By employing appropriate instrumental variables and conducting rigorous testing, we have addressed potential endogeneity concerns, thereby providing reliable and meaningful insights into the relationship between the variables of interest in our study.

5. 6. Propensity score matching

To address the potential influence of sample selection bias, we utilize the propensity score matching (PSM) approach in our study. Specifically, we implement a 1 ∶ 1 nearest neighbor matching with a matching radius of 0. 05, employing the categorization criterion of "Is a particular industry extremely polluting?" as the grouping variable. In the matching process, we incorporate a set of control variables as covariates to enhance the accuracy of the matching, including the business' s age (Age), its gearing (Leverage), Tobin' s Q (Q), net cash from investing activities (ICF), fixed assets (Fix), foreign ownership (QFII), dual employment (Dual), and audit opinion (Opinion). To ensure the validity of our matching procedure, we conduct tests to confirm the parallel trend hypothesis and the common support hypothesis. Upon confirming these assumptions, we reestimate the benchmark regression model and present the results in Table 11. The findings demonstrate that all regression coefficients for ESG are statistically significant and positive at the 1% level of significance. Furthermore, both the environmental (E) and social (S) components of ESG exhibit highly positive coefficients at the 1% significance level. By implementing the propensity score matching approach and conducting thorough tests, we effectively mitigate concerns regarding sample selection bias and enhance the robustness of our regression results. This methodological approach enables us to draw more reliable and credible conclusions regarding the positive impact of ESG, including its components, on firm-level green innovation.

Despite addressing the sample selection problem, the coefficient estimate of the governance component (G) in the regression remains statistically insignificant. This finding aligns with economic theory and empirical evidence, indicating a potential conflict between a company' s short-term corporate governance objectives and its long-term green innovation initiatives. This result suggests that companies may prioritize short-term financial gains and shareholder interests over sustainable and environmentally friendly practices, leading to a lack of significant impact of the governance component on green innovation. It highlights the need for companies to align their corporate governance goals with long-term sustainability objectives to foster an environment conducive to green innovation. By acknowledging the potential conflicts between short-term governance objectives and long-term sustainability goals, policymakers and organizations can work towards implementing governance frameworks and practices that incentivize and support sustainable innovation. This would help bridge the gap between corporate governance and green innovation, facilitating the adoption of environmentally responsible practices in the long run.

Table 11 PSM-benchmark regression results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	GIt+1	GIt+1	GIt+1	GIt+1	GCt+1	GCt+1	GCt+1	GCt+1
ESG	0. 260***				0. 504***			
	(4. 92)				(5. 98)			
E		0. 099***				0. 236***		
		(4. 06)				(4. 89)		
S			0. 138***				0. 260***	
			(3. 85)				(6. 10)	
G				0. 284				0. 456
				(1. 57)				(1. 05)
Constant	0. 016	0. 663***	0. 317	−0. 361	−0. 129	0. 867*	0. 460	−0. 509
	(0. 05)	(2. 69)	(1. 16)	(−0. 45)	(−0. 23)	(1. 84)	(0. 96)	(−0. 27)
Y/I/P FE	YES	YES	YES	YES	YES	YES	YES	YES
Observations	3, 379	2, 894	3, 274	3, 379	3, 379	2, 894	3, 274	3, 379
Adj R2	0. 109	0. 111	0. 103	0. 0975	0. 0817	0. 0798	0. 0724	0. 0690

Note: *** $P<0.01$; ** $P<0.05$; * $P<0.1$.

6. Conclusion and discussion

This empirical study investigates the relationship between ESG scores and company green innovation, concentrating on the ESG evaluation system' s micro-level environmental impact. The study makes use of panel data from Chinese listed businesses from 2010 to 2019, with a focus on corporate investment efficiency and government-enterprise relations. The following are the study' s principal findings: Firstly, the study reveals the existence of a strong relationship between ESG performance and corporate green innovation, which is consistent with past research findings. Secondly, the data indicate that ESG can help to promote corporate green innovation by improving investment performance and strengthening ties between the government and enterprises. These factors contribute to the creation of an environment conducive to sustainable and environmentally friendly practices. Thirdly, the study reveals that corporate attributes aligned with sustainability further strengthen the positive impact of ESG on corporate green innovation. Conversely, attributes associated with environmentally harmful practices tend to weaken the beneficial effect of ESG. Overall, this study enhances our understanding of the impact of ESG scores on corporate green innovation. By highlighting the role of investment efficiency and government-enterprise relations, as well as the influence of corporate attributes, it provides valuable insights for promoting sustainable and environmentally conscious practices within businesses.

We make the following suggestions based on our findings to improve the ESG evaluation system and encourage sustainable growth among microbusinesses: To promote both corporate development and green efforts, organizations should first adopt the ESG concept, manage environmental risks, boost their pro-environmental orientation, improve environmental transparency methods, and give non-financial green performance priority. Also, governments should put the concepts of green development into practice, create fiscal policies that are in line with the ESG evaluation system, offer financial assistance to green firms, enforce regulations on environmentally hazardous enterprises, and support green innovation activities that adhere to ESG standards. Moreover, in order to encourage participation in green innovation activities, authorities should develop specific policies that address the environmental risks that businesses confront and enhance the interchange of environmental information. Last but not least, institutional investors should emphasize the ESG performance of businesses, including ESG aspects in their investment plans, and accurately assess both internal and external environmental risks to give money in accordance with ESG ratings.

There are various limitations to this study. First off, it simply considers the micro-level environmental impact without thoroughly analyzing the broader role of the ESG evaluation system. Furthermore, it does not address the causes of corporate greenwashing or lessen its negative effects on green innovation. Future research may address these issues by looking at how the ESG rating system affects greenwashing practices including environmental performance, green production techniques, and green investment effectiveness. Future research can also create indicators to pinpoint the driving forces behind green innovation drifting so that the ESG evaluation system can be more accurately evaluated.

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