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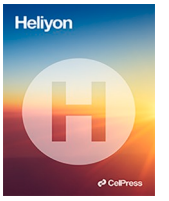

Research article

From ratings to action: The impact of ESG performance on corporate innovation

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ABSTRACT

This paper aims to investigate the relationship between ESG performance and corporate innovation using a sample of Chinese-listed companies from 2009 to 2021. The findings reveal that ESG performance is positively correlated with both the quantity and quality of corporate innovation. Further, we employed the causal step approach and the Sobel mediation effect test to empirically examine the mechanisms. The results support that ESG performance promotes corporate innovation by reducing agency problems, enhancing information disclosure, and improving internal corporate governance. Heterogeneity analysis indicates that the positive impact of ESG performance on corporate innovation is more pronounced among firms in the central and western regions, as well as those in heavily polluting industries. Notably, we corrected for the truncation-bias in the patent data. This study contributes to the expanding literature on the economic implications of ESG and holds policy implications for promoting the high-quality development of corporate innovation.

1. Introduction

Social issues, such as climate change, resource scarcity, and environmental pollution, have emerged as crises affecting the survival and development of humanity as a whole. The concept of sustainability has garnered widespread attention globally [1]. In 2004, the UN Global Compact introduced the Environmental, Social, and Governance (ESG) framework to the public, marking not only a moral and ethical investment philosophy but also one acknowledged for its impact on the economic performance of firms. ESG mandates that firms consider environmental protection, social responsibility, corporate governance, and traditional factors when making decisions [2,3]. The United Nations Principles for Responsible Investment (UNPRI), initiated in 2006, further underscore that the essence of ESG aligns closely with the inherent requirements of the sustainable development concept.

In this context, the emergence of ESG ratings becomes evident. These ratings developed by both business and non-profit organizations, serve to evaluate the alignment of corporate commitments, performance, business models, and structures with the Sustainable Development Goals (SDGs).[1] As major microeconomic market players, the impact of firms on society and the environment holds undeniable importance. In the face of global ecological deterioration and escalating uncertainty risks, stakeholders are progressively shifting their focus from firms' financial performance to their sustainable development performance, including environmental, social,

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[1] SDGs, the full name of Sustainable Development Goals, are 17 global development goals formulated by the United Nations to shift to a sustainable development path by thoroughly addressing the three dimensions of development-social, economic, and environmental-in an integrated manner between 2015 and 2030.

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and corporate governance [4–7]. Simultaneously, with the pursuit of high-quality sustainable development, innovation emerges as a principal avenue [8]. Consequently, the examination of how ESG performance influences corporate innovation has become a focal point of theoretical and academic scrutiny.

Existing research has explored the economic implications of corporate ESG performance, focusing on aspects such as corporate efficiency [9,10], financing constraints [11–13], capital structure [14,15], risk management [4,16,17], and firm value [6,18,19]. Furthermore, the validity of ESG performance in incentivizing corporate innovation has been widely demonstrated. Li et al. [20] and Chen et al. [21] found that ESG performance has a significant positive relationship with corporate innovation. Liu [22] and Tang [23] further analyzed the influence of ESG performance on corporate innovation strategies, including substantial and strategic innovation, and Tang [23] demonstrates that financing constraints and agency costs play a mediating role. Additionally, Li et al. [2] discussed the green innovation spillover effect emanating from ESG performance.

However, there is still considerable potential for expanding the analysis of mechanisms and heterogeneity between ESG performance and corporate innovation, and a significant research gap remains unexplored because prior studies have ignored truncation bias corrections for patent data in measuring corporate innovation.[2] In fact, on the one hand, innovation occupies a very important place in business operations. The existence of truncation bias in patent data has been pointed out and discussed by scholars [24,25]. Ignoring the effects of longer review cycles (even 3 years) and uncertainty delays on patent data may result in distorted study results. On the other hand, some firms choose to submit numerous invalid patent applications as a strategy to acquire policy support or secure market monopoly advantages [26,27], thus leading to a lack of synchronization between the quantity of innovation and the quality of innovation [28]. Therefore, it is important to measure corporate innovation cautiously as well as to focus on the impact of ESG performance on both the quantity and quality of corporate innovation.

We focus on China data for several reasons. First, as the world's second-largest economy, China is redirecting its focus towards social and environmental issues, transitioning away from a simplistic economic development model. Aligned with new development objectives like high-quality transformation and a dual-carbon strategy, China's demand for ESG practices has become more urgent. Second, ESG rating systems in China, although initiated relatively recently, necessitate ongoing efforts to enhance ESG capacity. This will align China's ESG ratings with international benchmarks and provide valuable insights for emerging market nations. Third, China is one of the most dynamic green finance regions in Asia and a major player in the global ESG market. Therefore, listed companies in China present a noteworthy experimental sample meriting systematic exploration concerning ESG ratings and corporate innovation within the context of China.

Thus, the purpose of this paper is to utilize truncated bias-corrected data for examining the impact of ESG performance on corporate innovation, exploring the underlying mechanisms, and further testing the heterogeneity of the impact based on the geographical location and industry characteristics of the firms. Using Chinese A-share listed companies from 2009 to 2021 as the research sample, we conducted an empirical investigation with a panel data model. The results show a significant positive correlation between ESG performance and corporate innovation. Mechanism tests suggest that ESG performance promotes corporate innovation by mitigating agency problems, enhancing information disclosure, and improving internal corporate governance. Heterogeneity analysis indicates that the positive impact of ESG performance on corporate innovation is more pronounced among firms located in the central and western regions, as well as those in heavily polluting industries. The findings remain robust after several robustness checks, including Heckman two-stage model regressions, alternative measures, lagged explanatory variables, and the inclusion of firm fixed effects.

The main motivation and contributions of this study are as follows. First, this paper enriches the research on the impact of sustainable development concepts on corporate innovation. While existing studies predominantly focus on the validity of ESG performance in incentivizing corporate innovation, fewer studies have focused on the mechanisms involved in the impact of ESG performance on corporate innovation. This study fills this gap by utilizing ESG ratings from various authoritative organizations and analyzing the specific mechanisms through which ESG performance relates to corporate innovation. The examination focuses on the perspectives of agency problems, information disclosure, and the level of corporate governance. This enables global firms to proactively consider sustaining their market presence in light of the new focus on investment orientation.

Second, it reveals heterogeneous factors influencing the relationship between ESG performance and corporate innovation. On the one hand, the incentive effect of ESG performance on corporate innovation may vary across business environments. On the other hand, the industry characteristics of firms also impact investors' confidence in the firms' sustainability, which is related to the acquisition of capital for innovation. Thus, we enrich the literature by conducting a cross-sectional analysis from two perspectives: geographic location and industry characteristics. As global regulatory agencies consistently enhance their ESG rating systems and global investors endeavor to refine investment strategies based on ESG performance, evaluating the potential heterogeneity in the innovative effects of ESG performance holds significant reference value for international markets, particularly in emerging market countries.

Third, the measurement of corporate innovation indicators considers truncation bias in patent data. The existence of truncation bias is an inherent limitation acknowledged in patent data [24,25]. However, in studies exploring the relationship between ESG performance and corporate innovation, it is common to directly utilize the number of patent applications as the basis for measuring corporate innovation, neglecting truncation bias correction. Following Dass et al. [24], we incorporate a fixed effects adjustment for patent truncation bias, which adjusts the number of patent citations based on technology category and year and performs better in

[2] Truncation bias arises when certain data points are excluded or truncated from a dataset, resulting from various factors, including limitations in the collection method and inherent constraints within the data. These factors may introduce errors or distortions in the statistical results. The truncation bias in patent data is due to possible delays in the publication of patent application information by the China National Intellectual Property Administration, as well as the fact that patent citations need to be accumulated for many years after a patent has been granted [24].

reducing the truncation bias in the number of citations. This approach helps mitigate the impact of truncation bias on empirical results.

Forth, this paper contributes novel empirical evidence guiding firms in making strategic decisions. As the world's largest developing country, China's economy is transitioning from a high-speed growth stage to a high-quality development stage. In pursuit of a sustainable development model, China has followed the international ESG development frontier, leading to the establishment of numerous ESG rating agencies. This is not only conducive to exploring the effectiveness of soft market regulation within the context of China but also provides a reference for directing capital and enterprises towards achieving long-term development. Furthermore, it provides valuable insights for other developing countries to deeply implement the concept of sustainable development.

The remainder of the paper is structured as follows. Section 2 summarizes the theoretical framework and develops the main hypotheses. Section 3 introduces the empirical research design. Section 4 reports the baseling results. Section 5 illustrates the indirect analyses, including mechanism analyses and cross-sectional analyses. Section 6 shows the robustness checks. Section 7 concludes the paper. Section 8 deals with limitations and directions for future research.

2. Literature review and hypothesis development

2.1. Theoretical framework

Upon reviewing the previous literature, we have formulated a theoretical framework to underpin our subsequent studies. First of all, stakeholder theory is one of the recognized theories in the field of ESG subject research [1]. Compared with traditional shareholder supremacy, it believes that the survival and development of any company are inseparable from the input or participation of various stakeholders and that firms not only pursue the interests of certain subjects but the interests of stakeholders as a whole [29]. Stakeholders include shareholders, creditors, employees, consumers, suppliers, and other trading partners. Additionally, external organizations such as government departments, local residents, communities, the media, and those directly or indirectly effected by the firms' activities, such as the natural environment. They share business risks and carry out supervision. Therefore, firms must consider their interests, accept their constraints in their business decisions, and promote sustainability by cultivating positive relationships with stakeholders. Contrary to the traditional theory that the sole objective of a firm is to maximize economic profits [30], the emergence of stakeholder theory introduces a broader perspective. In addition to economic goals, firms must also take on social and environmental responsibilities, which are necessary for achieving sustainability.

Secondly, signaling theory serves as an effective tool for addressing information asymmetry and offers an explanation for the governance effectiveness of ESG. Its basic idea is to reveal the information asymmetry between information superior and information inferior parties through signaling [31]. In a market economy, information asymmetry is common, with the information superior party possessing more inside information, placing the information inferior party at a disadvantage. The signaling theory has a wide range of applications. Firms can publicize their strengths and characteristics and send out signals to the outside world that they are performing effectively, which will draw in more investor attention and development resources.

2.2. Hypothesis development

Amidest the global commitment to the low-carbon transition, ESG investment is gaining momentum globally and becoming the common demand of stakeholders such as investors, governments, and the public [4–7]. According to Bloomberg Intelligence, global ESG assets reached $37.8 trillion in 2021 and are expected to reach $53 trillion by 2025, accounting for one-third of the world's total managed investments. ESG performance is increasingly becoming a vital management tool for firms striving for sustainable growth.

Porter's hypothesis argues that although environmental regulation may cause market failure, appropriate and strict environmental regulation can guide and stimulate firms to engage in technological and organizational innovation, and this view has been verified by many scholars [32–34]. With growing social concern about environmental issues, the role of environmental performance as a crucial component of social responsibility information is gaining increasing significance in the capital market [35]. For enterprises, environmental management is one of the means of strategic management. Positive disclosure of environmental information helps to foster communication between enterprises and local governments, the media, and the public, contributes to maintaining a favorable reputation and image, and enhances the basis of legitimacy [36]. Environmentally friendly practices not only encourage firms to eliminate high-energy-consuming and high-polluting production technologies and backward production capacity but also signal to the capital market that the firm is actively fulfilling its social responsibility. Simultaneously, it demonstrates the firm's commitment and capability to develop in a sustainable way, which will help to enhance investor confidence and reduce the cost of corporate innovation [37].

The impact of human capital on enterprise innovation is undeniable. Employees with specialized skills and knowledge play a crucial role in assisting firms in developing more competitive products and services [38]. Firms can further stimulate the innovation spirit and work enthusiasm of employees through a reward system, team-building initiatives, employee training, etc., so as to improve the innovation ability of firms [39]. Moreover, maintaining a stable supplier relationship holds significance, not only in ensuring the quantity and quality of the firms' products but also in reducing the time and energy consumption in searching for new suppliers and negotiating contracts. This reduction in transaction costs and supply risks is an important assurance for the smooth progress of corporate innovation [40].

An effective corporate governance system promotes the mutual harmonization of interests between managers and shareholders and enhances managers' willingness to take risks [41]. Managers' overconfidence not only corrects their underinvestment in innovation due to risk-averse motives but also captures investment projects with promising return prospects, which in turn increases innovation

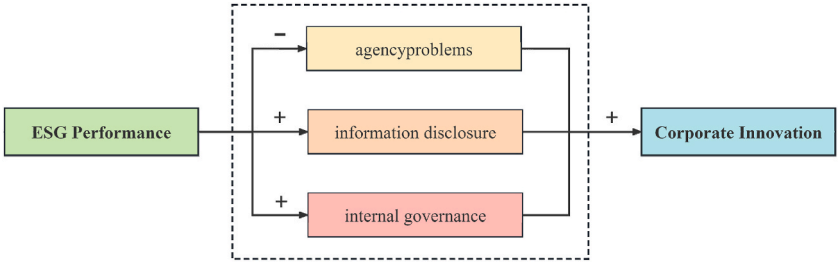

Fig. 1. Mechanism analyses.

output [42]. Shareholders' meetings, boards of directors, supervisory boards, and senior management are responsible for formulating strategic plans for firms and providing financial, human, and technological resources for innovation. The signals of social responsibility conveyed through ESG practices can also lead to higher risk tolerance and trust among external stakeholders [37].

In conclusion, numerous indicators comprising the ESG evaluation system are beneficial to corporate innovation. Therefore, we propose hypothesis H1.

Hypothesis H1. ESG performance has a positive impact on corporate innovation.

ESG ratings have the potential to stimulate management's willingness to engage in corporate innovation by reducing the principal-agent problem within firms. In a management system where ownership and operation rights are distinct, the principal-agent problem tends to exist between owners and operators due to information asymmetry and other factors [43]. In the background of the increasingly accelerated pace of ecological civilization construction and facing the dual pressure of government environmental regulation and performance assessment, management prefers market arbitrage activities with short investment cycles and high returns to longer-term and riskier R&D and innovation activities [44]. However, the emergence of ESG ratings has altered this trend [45]. On one hand, ESG performance encourages management to partake in environmental governance and assume more social responsibility. This prompts management to focus on long-term firm value enhancement, thereby increasing risk tolerance for corporate innovation [46]. On the other hand, ESG engagement operates as a deterrent to managerial misconduct, including information disclosure violations, insider trading, illegal misappropriation of funds, stock price manipulation, etc. [47,48]. Especially under the supervision of relevant stakeholders such as investors, the government, and the public, management accelerates the pace of corporate transformation and upgrading, actively promoting the firm's innovative activities. Accordingly, we propose H2a.

Hypothesis H2a. Agency problems mediate the relationship between ESG performance and corporate innovation.

ESG ratings could prompt firms to improve the transparency of corporate information by improving the quality of information [36] so as to obtain financial support for corporate innovation. Affected by the characteristics of large capital investment, high risk, and long cycle, the ability to obtain sufficient financial support has become one of the important factors restricting the development of corporate innovation. Especially in the background of increasingly fierce competition in the market and increasingly strict external regulation, internal and external information discrepancies prevent investors from obtaining adequate information on firms' environmental responsibility performance [49]. ESG ratings comprehensively reflect the operating conditions of firms from multiple perspectives, providing an opportunity for firms to improve information transparency [12]. It is well known that information risk is the root cause of the financing constraint problem [50], and high-quality disclosure can reduce the information asymmetry between borrowers and lenders [51–54]. Therefore, ESG ratings can help firms improve the quality of information and increase the transparency of corporate information so as to obtain financial support for innovation activities. We thus propose H2b.

Hypothesis H2b. Information disclosure mediates the relationship between ESG performance and corporate innovation.

Internal governance is concerned with the distribution of power and responsibility within firms, encompassing mutual checks and balances and supervision between different internal stakeholders to ensure the efficiency and fairness of the firms' decision-making [55]. In addition, it ensures the timeliness of corporate risk identification, the effectiveness of monitoring mechanisms, and the compliance of the operation system [56]. Efficient internal governance aids firms in accurately assessing their strengths and weaknesses, enabling them to formulate an innovation strategy aligned with their realities, thereby reducing innovation uncertainty. ESG factors reflect the external risks and opportunities faced by firms, such as climate change, policy reforms, corporate compliance issues, etc., and provide a reference for firms to strengthen risk management and enhance stability and competitiveness. As an important part of non-financial performance, ESG performance objectively mirrors firms' sustainability and social responsibility [57], contributing to the improvement of the effectiveness of enterprises' internal governance. In conclusion, ESG practices prompt firms to strengthen internal control, exerting a positive impact on corporate innovation. Consequently, we propose hypothesis H2c.

Hypothesis H2c. Internal governance mediates the relationship between ESG performance and corporate innovation.

The above deduction process is shown in Fig. 1.

Table 1
Frequency distribution by industry.

Panel A: By industry		
Industry	Full sample	Proportion of sample size (%)
Agriculture, forestry, animal husbandry and fishery (A)	494	1.43
Mining industry (B)	821	2.37
Manufacturing industry (C)	22,467	64.99
Industry of electric power, heat, gas and water production and supply (D)	1128	3.26
Construction industry (E)	914	2.64
Wholesale and retail industry (F)	1784	5.16
Transport, storage and postal service industry (G)	1031	2.98
Accommodation and catering industry (H)	110	0.32
Industry of information transmission, software and information technology services (I)	2221	6.42
Real estate industry (K)	1453	4.20
Leasing and commercial service industry (L)	429	1.24
Scientific research and technical service industry (M)	356	1.03
Water conservancy, environment and public facility management industry (N)	444	1.28
Industry of resident service, repair and other services (O)	31	0.09
Education (P)	37	0.11
Health and social work (Q)	77	0.22
Industry of culture, sports and entertainment (R)	452	1.31
Diversified industries (S)	320	0.93
Total	34,569	100

Note: Table 1 presents the frequency distribution by industry. These industry names and codes refer to the *guideline on Industry Classification of Listed Companies* formulated by SEC.

3. Research design

3.1. Sample and data

The initial sample includes all Chinese A-share listed firms during 2009–2021. The reason for starting in 2009 is that the ESG rating in China started year.[3] We further exclude dates from the financial industry, observations with a market type of B-share, instances with less than one year of operation, and observations with missing values of core variables. The ESG rating date provided by Huazheng Index Information Service Company is included in the Wind database, patent data comes from the CNRDS and CSMAR databases, internal control index is obtained from DIB's Understanding of Enterprise Risk Management and Control, and other financial date is collected from the CSMAR databases. We finally obtained a total of 34,569 firm-year observations, including 4333 firms. To mitigate the impact of outliers, all continuous variables are winorized at the 1% and 99% levels.

3.2. Model specification and variable definitions

This paper utilizes panel date to empirically test the impact of ESG performance on corporate innovation. The following benchmark regression model is constructed for the empirical tests:

$$Patent1\ (Patent2)_{i,t} = \alpha_0 + \alpha_1 ESG_{i,t} + \delta_1 Controls_{i,t} + Year + Industry + \varepsilon_{i,t} \quad (1)$$

Where the variable subscripts i and t represent firm i in year t. The independent variable *ESG* represents the ESG ratings index of firms. There are a total of 9 grades of ESG performance, including C, CC, CCC, B, BB, BBB, A, AA, and AAA. Following Huang et al. [58], we assign the above ratings in order 1–9, the larger the value, the better the firm's ESG performance.

The dependent variables *Patent1* and *Patent2* represent the quantity and quality of corporate innovation respectively. We choose the number of invention patent applications and citations, which are more reflective of originality [27], as the basis for measuring innovation outputs. On one hand, the quantity of corporate innovation *Patent1* is measured by the natural logarithm of the number of invention patent applications plus one. We also correct for truncation bias in the number of patent applications by front-loading *Patent1* by one period and two periods, respectively, in our robustness tests. Specifically, in cases where the firm's patent application data is missing, we assume that the firm has no patent output in that year and record the value as 0. On the other hand, the quality of corporate innovation *Patent2* is measured by the number of invention patents per unit that are cited by others. It should be noted that there is a truncation bias in *Patent2*, indicating that the earlier the year the patent is granted, the larger the number of patents cited by others. Therefore, following previous literature [24], we adjust the number of citations for the fixed effects of each technology class,

[3] ESG data for China is provided by Shanghai Huazheng Index Information Service Co., Ltd., a China-based third-party data provider specializing in comprehensive indexing and indexing investment services. With reference to the international mainstream methodology and practical experience, and taking into account China's national conditions and the characteristics of the capital market, they comprehensively evaluate the ESG performance of firms based on 3 pillars, 16 themes, and 44 key indicators, which are characterized by a wide range of coverage as well as timeliness.

Table 2
Variable definitions.

Variable	Definitions
Patent1	Alternative measure of corporate innovation, defined as the natural logarithm of the number of invention patent applications plus 1
Patent2	Alternative measure of corporate innovation, defined as the average number of citations per invention patent by others
ESG	Alternative measure of ESG performance, measured by the assignment score, which is obtained by assigning the nine grades including C, CC, CCC, B, BB, BBB, A, AA, and AAA as 1 to 9.
ESG_b	Alternative measure of ESG performance, measured by the scores from Bloomberg
Size	Firm size, measured by the natural logarithm of total assets
Lev	Firm leverage, measured by the ratio of debt to total assets
Q	Tobin's Q, measured by the ratio of the market value of total assets to the book market of total assets
ROA	Firm performance, measured by the net income divided by total assets
Estage	Firm age, measured by the natural logarithm of the number of years since the firm went public plus 1
*Top*1	Ownership Concentration, measured by the number of shares owned by the largest shareholder divided by the total number of outstanding shares
SOE	State ownership indicator, equal to 1 if the firm is state-owned and 0 for non-state-owned firms
Board	Board size, measured by the natural logarithm of the number of directors on the board
Indep	Board independence, measured by the number of independent directors divided by the total number of directors
Pay	Executive compensation, measured by the natural logarithm of the average compensation of the top three highest-paid executives plus 1
Mshare	Managerial ownership, measured by the absolute value of discretionary accruals calculated by the modified Jones model
AbsDa	Information disclosure, absolute value of discretionary accruals following Dechow [66]
IC	Internal control index, measured by the scores from DIB

Table 3
Summary statistics.

Variables	N	Mean	Std.	Min	Median	Max
ESG	34569	4.084	1.122	1	4	8
Patent1	34569	1.768	1.555	0	1.609	6.091
Patent2	34569	0.963	1.139	0	0.700	5.219
Size	34569	22.12	1.308	18.88	21.94	26.08
Lev	34569	0.430	0.214	0.050	0.420	0.987
Q	34569	2.100	1.436	0.862	1.641	9.988
ROA	34569	0.036	0.071	−0.365	0.038	0.220
Estage	34569	2.866	0.352	1.609	2.890	3.497
Top1	34569	34.69	14.79	8.540	32.45	75
SOE	34569	0.367	0.482	0	0	1
Board	34569	2.242	0.177	1.792	2.303	2.773
Indep	34569	37.54	5.319	33.33	35.71	57.14
Pay	34569	14.46	0.726	12.54	14.44	16.47

Note: Variable definitions are shown in Table 2.

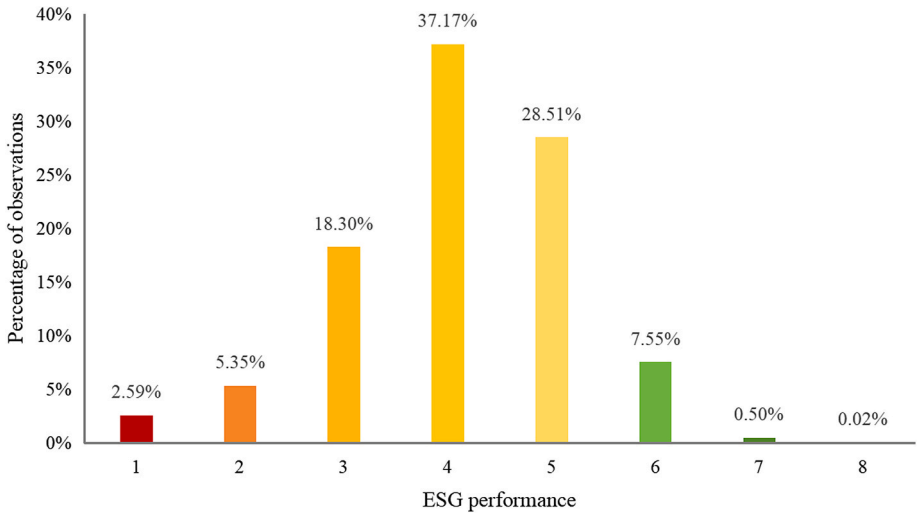

Fig. 2. Frequency distribution of ESG performance.

Table 4
Baseline results: The impact of ESG performance on corporate innovation.

Variables	(1)	(2)	(3)	(4)
	Patent1	Patent2	Patent1	Patent2
ESG	0.278***	0.099***	0.121***	0.049***
	(21.64)	(14.41)	(11.75)	(7.16)
Size			0.534***	0.186***
			(29.99)	(19.78)
Lev			−0.157**	−0.212***
			(-2.11)	(-4.77)
Q			0.066***	0.027***
			(7.28)	(4.69)
ROA			0.318**	−0.070
			(2.24)	(-0.62)
Estage			−0.176***	−0.066***
			(-3.53)	(-2.62)
Top1			−0.001	−0.002***
			(-0.93)	(-3.09)
SOE			0.141***	−0.002
			(3.81)	(-0.09)
Board			0.169*	0.100**
			(1.71)	(1.99)
Indep			0.001	−0.002
			(0.17)	(-1.18)
Pay			0.165***	0.045***
			(7.07)	(3.54)
Constant	0.633***	0.560***	−12.924***	−3.872***
	(12.31)	(19.09)	(-26.48)	(-16.19)
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
N	34,569	34,569	34,569	34,569
R^2	0.053	0.011	0.281	0.050

Note: Variable definitions are shown in Table 2. T statistics are in parentheses and the standard errors are clustered at the firm level. ***, **, * denote significance at the 1%, 5%, and 10% levels, respectively.

industry category, and year. Specifically, we first classify invention patents according to the *International Patent Classification* (IPC), which is an internationally recognized tool for classifying and searching patent documents. Second, we calculated the average number of citations per invention since the patent was granted. Third, we divide the number of invention patent citations by others for each firm by the average number of invention patent citations in the same technology class, industry category, and granted in the same year, and then divide it by the number of invention patents of firms in the same year, respectively. Finally, we obtain *Patent2*, which is the measure of corporate innovation quality.

Controls is a group of control variables in Equation (1). We exclude other factors by controlling variables to identify the net effect related to ESG performance and also minimize endogeneity. Prior studies have shown that larger and more established firms possess valuable resources and experience that contribute to their innovation activities [59,60]. Additionally, higher market value and return on assets are associated with improved growth potential and business performance, which is conducive to greater investment in innovation [61]. However, a higher asset liability ratio may lead to increased limitations on investment in innovation, and the impact of ownership structures and property rights on corporate innovation is intricate, with inconsistent conclusions. The characteristics of the board and management also play a role. An expanded board size may escalate disagreement, potentially influencing the efficiency of firms' investment in innovation [62]. Moreover, confident managers are more likely to engage in high-risk innovation activities [42]. Thus, following previous literature [63–65], we introduced firm size (*Size*), financial leverage (*Lev*), Tobin's Q (*Q*), return on assets (*ROA*), firm age (*Estage*), controlling shareholder's ownership (*Top1*), the nature of the enterprise (*SOE*), the size of the board of directors (*Board*), the independence of the board (*Indep*) and the percentage of top three executives' compensation (*Pay*). In addition, in order to control for the influences of industry and macroeconomic conditions on corporate innovation, we also control for year fixed effects (*Year*) and industry fixed effects (*Industry*). The definition of each variable is shown in Table 2.

3.3. Summary statistics

Table 3 reports the results of descriptive statistics for the main variables. Fig. 2 shows the frequency distribution of ESG performance. From 2009 to 2021, the minimum value of the ESG performance (*ESG*) is 1, the maximum value is 8, the mean is 4.084, and the standard deviation is 1.122. From Fig. 1, it can be seen that the ESG performance of most companies is in the middle of the pack, with more room for improvement. The maximum value of the quantity of corporate innovation (*Patent1*) is 6.091, the minimum value is 0, and the mean is 1.768, with a standard deviation of 1.555. The maximum value of the quality of corporate innovation (*Patent2*) is 5.219, the minimum value is 0, the mean is 0.963, and the standard deviation is 1.139, indicating that there are large differences in innovation outputs among different firms. The descriptive statistics of the remaining variables are basically consistent with the existing

Table 5A
Mechanism tests: Agency problems.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	Patent1	Mshare	Patent1	Patent2	Mshare	Patent2
ESG	0.121***	1.938***	0.116***	0.048***	1.938***	0.045***
	(11.57)	(12.80)	(11.08)	(7.00)	(12.80)	(6.54)
Mshare			0.002***			0.002***
			(2.93)			(3.32)
Size	0.533***	−3.495***	0.541***	0.186***	−3.495***	0.191***
	(29.86)	(-15.29)	(30.04)	(19.29)	(-15.29)	(19.46)
Lev	−0.159**	−6.526***	−0.144*	−0.226***	−6.526***	−0.216***
	(-2.12)	(-5.80)	(-1.92)	(-5.01)	(-5.80)	(-4.79)
Q	0.064***	−2.217***	0.069***	0.027***	−2.217***	0.031***
	(7.13)	(-17.70)	(7.66)	(4.53)	(-17.70)	(5.01)
ROA	0.337**	26.255***	0.276*	−0.058	26.255***	−0.098
	(2.35)	(12.41)	(1.91)	(-0.50)	(12.41)	(-0.85)
Estage	−0.162***	−8.550***	−0.142***	−0.066***	−8.550***	−0.053**
	(-3.23)	(-10.38)	(-2.82)	(-2.60)	(-10.38)	(-2.08)
Top1	−0.001	−0.008	−0.001	−0.002***	−0.008	−0.002***
	(-0.93)	(-0.47)	(-0.92)	(-2.98)	(-0.47)	(-2.96)
SOE	0.146***	−13.665***	0.178***	0.005	−13.665***	0.026
	(3.91)	(-30.06)	(4.54)	(0.28)	(-30.06)	(1.30)
Board	0.179*	−1.651	0.183*	0.086*	−1.651	0.089*
	(1.80)	(-1.22)	(1.84)	(1.70)	(-1.22)	(1.75)
Indep	0.000	0.090**	0.000	−0.002	0.090**	−0.002
	(0.09)	(2.16)	(0.02)	(-1.16)	(2.16)	(-1.25)
Pay	0.164***	−0.295	0.164***	0.044***	−0.295	0.044***
	(6.96)	(-0.84)	(7.00)	(3.37)	(-0.84)	(3.42)
Constant	−12.907***	123.586***	−13.195***	−3.804***	123.586***	−3.992***
	(-26.42)	(19.56)	(-26.40)	(-15.80)	(19.56)	(-16.13)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
N	33,502	33,502	33,502	33,502	33,502	33,502
R^2	0.289	0.280	0.279	0.048	0.280	0.049
Sobel Z	5.793***			4.310***		

Note: Variable definitions are shown in Table 2. T statistics are in parentheses and the standard errors are clustered at the firm level. ***, **, * denote significance at the 1%, 5%, and 10% levels, respectively.

literature and are all within a reasonable range.

4. Baseline results

Table 4 reports the results of the benchmark regression of ESG performance on corporate innovation. The estimated coefficients on the quantity of corporate innovation (*Patent1*) and the quality of corporate innovation (*Patent2*) in columns (3) and (4) are 0.121 and 0.049, and both of them are significantly positive at the 1% level after controlling for year-fixed effects and industry-fixed effects. The above results indicate that ESG performance positively affects corporate innovation. In terms of economic implications, higher ESG ratings lead to an average increase in the quantity of corporate innovation output by about 12.1% and in the quality of corporate innovation output by about 4.9%. Thus, excellent ESG performance has a positive impact on corporate innovation, supporting Hypothesis H1.

5. Additional analyses

5.1. Mechanism analyses

In our theoretical analysis, we hypothesize that ESG performance may affect corporate innovation through three channels: agency problems, information risk, and corporate governance level. Therefore, referring to previous studies [67], we adopt the causal step approach to test the mediating effects, and the specific model is shown below:

$$Patent1\ (Patent2)_{i,t} = \alpha_0 + \alpha_1 ESG_{i,t} + \delta_1 Controls_{i,t} + Year + Industry + \varepsilon_{i,t} \quad (2A)$$

$$M_{i,t} = \gamma_0 + \gamma_1 ESG_{i,t} + \delta_2 Controls_{i,t} + Year + Industry + \varepsilon_{i,t} \quad (2B)$$

$$Patent1\ (Patent2)_{i,t} = \varphi_0 + \varphi_1 ESG_{i,t} + \varphi_2 M_{i,t} + \delta_3 Controls_{i,t} + Year + Industry + \varepsilon_{i,t} \quad (2C)$$

where $M_{i,t}$ is the mediation variable that refers to different variables in three mechanism tests. Other control variables remain

Table 5B
Mechanism tests: Information disclosure.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	Patent1	AbsDa	Patent1	Patent2	AbsDa	Patent2
ESG	0.120***	−0.001**	0.120***	0.047***	−0.001**	0.047***
	(10.82)	(-2.51)	(10.78)	(6.64)	(-2.51)	(6.60)
AbsDa			−0.430***			−0.245***
			(-4.01)			(-2.97)
Size	0.538***	−0.003***	0.537***	0.176***	−0.003***	0.175***
	(28.21)	(-4.56)	(28.20)	(17.29)	(-4.56)	(17.19)
Lev	−0.196**	0.022***	−0.186**	−0.197***	0.022***	−0.192***
	(-2.39)	(6.80)	(-2.27)	(-4.00)	(6.80)	(-3.87)
Q	0.059***	0.004***	0.060***	0.026***	0.004***	0.027***
	(6.18)	(9.70)	(6.37)	(3.99)	(9.70)	(4.15)
ROA	0.397**	−0.167***	0.325**	−0.068	−0.167***	−0.109
	(2.45)	(-13.97)	(1.99)	(-0.52)	(-13.97)	(-0.84)
Estage	−0.195***	−0.000	−0.195***	−0.074***	−0.000	−0.074***
	(-3.61)	(-0.11)	(-3.61)	(-2.69)	(-0.11)	(-2.70)
Top1	−0.001	0.000**	−0.001	−0.002***	0.000**	−0.002***
	(-0.58)	(2.02)	(-0.55)	(-2.76)	(2.02)	(-2.73)
SOE	0.157***	−0.010***	0.152***	0.004	−0.010***	0.001
	(4.09)	(-9.01)	(3.97)	(0.20)	(-9.01)	(0.07)
Board	0.161	−0.011***	0.156	0.122**	−0.011***	0.120**
	(1.54)	(-3.34)	(1.50)	(2.33)	(-3.34)	(2.29)
Indep	0.001	−0.000	0.001	−0.001	−0.000	−0.001
	(0.42)	(-0.65)	(0.41)	(-0.41)	(-0.65)	(-0.42)
Pay	0.162***	0.003***	0.163***	0.045***	0.003***	0.046***
	(6.58)	(3.55)	(6.64)	(3.37)	(3.55)	(3.43)
Constant	−12.908***	0.105***	−12.863***	−3.722***	0.105***	−3.696***
	(-24.86)	(6.70)	(-24.81)	(-14.71)	(6.70)	(-14.63)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
N	31,079	31,079	31,079	31,079	31,079	31,079
R^2	0.279	0.046	0.279	0.045	0.046	0.045
Sobel Z	1.985***			2.044***		

Note: Variable definitions are shown in Table 2. T statistics are in parentheses and the standard errors are clustered at the firm level. ***, **, * denote significance at the 1%, 5%, and 10% levels, respectively.

consistent with Equation (1).

The main procedure of the mediation effect test involves several steps. First, the overall impact of ESG performance on corporate innovation is assessed through Equation (2A). If the regression coefficient α_1 is statistically significant, indicating a notable effect of ESG performance on corporate innovation, the analysis proceeds to the next step. Second, in Equation (2B), the mediation variable (*M*) is regressed on the explanatory variable (*ESG*). Third, building on Equation (2A), both the explanatory variable (*ESG*) and the mediation variable (*M*) are regressed in Equation (2C). The significance of the regression coefficient γ_1 for the explanatory variable (*ESG*) in Equation (2B) and the regression coefficient φ_2 for the mediation variable (*M*) in Equation (2C) concurrently suggests the presence of a mediation effect. If either the regression coefficients γ_1 or φ_2 is not statistically significant, further judgment is required with the help of the Sobel test. In this paper, we have conducted the Sobel test for all the mechanisms to ensure the robustness of the results.

5.1.1. The channel of agency problems

In previous analyses, we hypothesized that ESG performance can stimulate management's willingness to engage in corporate innovation by alleviating the agency problem within the firm, thus promoting corporate innovation. Studies have shown that executive shareholding strengthens the synergy of interests between shareholders and management, reduces agency conflicts in the firm, and realizes "incentive compatibility" [68]. We adopt the management shareholding ratio (*Mshare*) to measure the agency cost of enterprises. The higher the percentage of management shareholding, the fewer the potential agency issues.

Table 5A reports the regression results for agency costs (*Mshare*) as a mediating variable. It can be seen that the estimated coefficients of *ESG* in columns (2) and (5) are significantly positive at the 1% level, indicating that firms with higher ESG performance have fewer agency problems. The coefficients on the mediating variable *Mshare* in columns (3) and (6) are both significantly positive at the 1% level. Meanwhile, the *ESG* coefficient remains significantly positive at the 1% level. In addition, the Sobel Z-statistics are both significant at the 1% level, indicating that the mediation effect is supported by the Sobel test. Therefore, the reduction of agency problems is one of the mechanisms of ESG performance influencing corporate innovation, supporting Hypothesis H2a.

5.1.2. The channel of information disclosure

ESG ratings will help companies improve the quality of information disclosure and increase the transparency of corporate information, thus obtaining financial support for innovative activities and promoting corporate innovation. To test this mechanism, we use

Table 5C
Mechanism tests: Internal governance.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	Patent1	IC	Patent1	Patent2	IC	Patent2
ESG	0.114***	0.299***	0.102***	0.037***	0.299***	0.029***
	(8.35)	(17.78)	(7.30)	(4.07)	(17.78)	(3.19)
IC			0.039***			0.026***
			(4.42)			(4.02)
Size	0.481***	0.170***	0.475***	0.175***	0.170***	0.170***
	(19.20)	(7.35)	(18.92)	(11.77)	(7.35)	(11.47)
Lev	−0.097	−0.857***	−0.063	−0.225***	−0.857***	−0.203***
	(-0.97)	(-6.55)	(-0.64)	(-3.61)	(-6.55)	(-3.24)
Q	0.040***	−0.069***	0.042***	0.015*	−0.069***	0.017**
	(3.31)	(-5.16)	(3.52)	(1.85)	(-5.16)	(2.07)
ROA	0.447***	6.081***	0.210	−0.019	6.081***	−0.180
	(2.64)	(23.45)	(1.23)	(-0.13)	(23.45)	(-1.22)
Estage	−0.136**	−0.164***	−0.129**	−0.062*	−0.164***	−0.058*
	(-2.08)	(-3.24)	(-1.98)	(-1.82)	(-3.24)	(-1.70)
Top1	−0.002	0.005***	−0.002*	−0.002***	0.005***	−0.002***
	(-1.54)	(4.40)	(-1.67)	(-3.08)	(4.40)	(-3.25)
SOE	0.064	−0.014	0.065	−0.035	−0.014	−0.034
	(1.23)	(-0.32)	(1.24)	(-1.28)	(-0.32)	(-1.27)
Board	0.229	0.060	0.227	0.089	0.060	0.087
	(1.64)	(0.48)	(1.63)	(1.26)	(0.48)	(1.24)
Indep	−0.001	0.000	−0.001	−0.001	0.000	−0.001
	(-0.24)	(0.13)	(-0.24)	(-0.57)	(0.13)	(-0.58)
Pay	0.222***	0.085***	0.219***	0.053***	0.085***	0.051***
	(7.07)	(3.01)	(6.97)	(2.96)	(3.01)	(2.84)
Constant	−12.503***	0.591	−12.526***	−3.576***	0.591	−3.592***
	(-17.86)	(1.04)	(-17.90)	(-10.49)	(1.04)	(-10.55)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
N	19,193	19,193	19,193	19,193	19,193	19,193
R^2	0.231	0.262	0.283	0.038	0.262	0.039
Sobel Z	6.186**			4.731**		

Note: Variable definitions are shown in Table 2. T statistics are in parentheses and the standard errors are clustered at the firm level. ***, **, * denote significance at the 1%, 5%, and 10% levels, respectively.

the Jones model modified by Dechow [66] to calculate discretionary accruals (*Da*) and take its absolute value as a measure of the quality of information disclosure (*AbsDa*). The larger the absolute value of discretionary accruals, the larger the scope for surplus management, the lower the quality of accounting information, and the lower the information risk. The model is shown below:

$$\frac{TA_{i,t}}{A_{i,t-1}} = \gamma_0 \frac{1}{A_{i,t-1}} + \gamma_1 \frac{\Delta REV_{i,t}}{A_{i,t-1}} + \gamma_2 \left(\frac{PPE_{i,t}}{A_{i,t-1}}\right) + \varepsilon_{i,t} \tag{3A}$$

$$NDA_{i,t} = \widehat{\gamma}_0 \frac{1}{A_{i,t-1}} + \widehat{\gamma}_1 \frac{\Delta REV_{i,t} - \Delta REC_{i,t}}{A_{i,t-1}} + \widehat{\gamma}_2 \left(\frac{PPE_{i,t}}{A_{i,t-1}}\right) \tag{3B}$$

$$DA_{i,t} = \frac{TA_{i,t}}{A_{i,t-1}} - NDA_{i,t} \tag{3C}$$

where *TA* is the difference between operating profit and net cash flow from operating activities, *NDA* is non-manipulative accrual profit, *DA* is manipulative accrual profit, $\triangle REV$ is the change in operating revenues, $\triangle REC$ is the change in accounts receivable, *PPE* is net fixed assets, and A_{t-1} is the firm's total assets at the end of year t-1. Other control variables in Equation (3A), Equation (3B), and Equation (3C) remain consistent with Equation (1).

Table 5B reports the regression results for information disclosure (*AbsDa*) as a mediating variable. It can be seen that the estimated coefficients of *ESG* in columns (2) and (5) are significantly negative at the 1% level, indicating that strong ESG performance enhances a firm's information disclosure. The coefficients on the mediating variable *AbsDa* in columns (3) and (6) are both significantly negative at the 1% level. Meanwhile, the coefficient of *ESG* remains significantly positive at the 1% level. In addition, the Sobel Z-statistics are both significant at the 1% level, indicating that the mediation effect is supported by the Sobel test. Thus, the reduction of information disclosure is one of the mechanisms of ESG performance influencing corporate innovation, supporting Hypothesis H2b.

Table 6A
Cross-sectional analysis: Geographic location.

Variables	(1)	(2)	(3)	(4)
	Patent1	Patent1	Patent2	Patent2
	Eastern regions	Central & Western regions	Eastern regions	Central & Western regions
ESG	0.114***	0.128***	0.035***	0.071***
	(9.12)	(7.05)	(4.28)	(5.90)
Size	0.560***	0.470***	0.189***	0.185***
	(27.12)	(15.19)	(16.92)	(10.39)
Lev	−0.151*	−0.006	−0.234***	−0.118
	(-1.68)	(-0.05)	(-4.35)	(-1.50)
Q	0.072***	0.048***	0.033***	0.022**
	(6.53)	(3.30)	(4.47)	(2.30)
ROA	0.429**	0.322	−0.075	−0.012
	(2.52)	(1.33)	(-0.54)	(-0.06)
Estage	−0.110*	−0.281***	−0.020	−0.179***
	(-1.86)	(-3.25)	(-0.68)	(-3.61)
Top1	−0.002	0.001	−0.002***	−0.001
	(-1.55)	(0.33)	(-3.38)	(-0.53)
SOE	0.124***	0.152**	−0.006	0.005
	(2.62)	(2.49)	(-0.23)	(0.16)
Board	0.149	0.257	0.094	0.105
	(1.21)	(1.60)	(1.56)	(1.14)
Indep	0.002	−0.002	−0.002	−0.002
	(0.59)	(-0.36)	(-0.96)	(-0.81)
Pay	0.174***	0.093**	0.053***	0.003
	(5.96)	(2.43)	(3.36)	(0.12)
Constant	−13.702***	−10.552***	−4.065***	−3.159***
	(-23.44)	(-12.58)	(-13.84)	(-7.34)
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
N	24,157	10,410	24,157	10,410
R^2	0.295	0.238	0.047	0.053
Between-group diff.	−0.015**		−0.036***	

Note: Variable definitions are shown in Table 2. T statistics are in parentheses and the standard errors are clustered at the firm level. ***, **, * denote significance at the 1%, 5%, and 10% levels, respectively.

5.1.3. The channel of internal governance

ESG rating will prompt firms to strengthen internal control and improve the efficiency of enterprise resource allocation, thus improving the quantity of innovation output and the quality of innovation output. Following previous literature [69], we adopt the DIB internal control index (*IC*) as a measure of the firm's internal governance level,[4] and the larger the internal control index (*IC*) is, the higher the firm's internal governance level is.

Table 5C reports the regression results for the internal control index score (*IC*) as a mediating variable. It can be seen that the estimated coefficients of *ESG* in columns (2) and (5) are significantly positive at the 1% level, indicating that improved ESG performance drives firms to strengthen their internal controls. The coefficients on the mediating variable *IC* in columns (3) and (6) are both significantly positive at the 1% level, and more importantly, the *ESG* coefficient remains significantly positive at the 1% level. In addition, the Sobel Z-statistics are both significant at the 5% level, indicating that the mediation effect is supported by the Sobel test. We can conclude that the improvement of internal control level is one of the mechanisms of ESG performance influences corporate innovation, supporting Hypothesis H2c.

5.2. Cross-sectional analyses

5.2.1. The effect of geographic location

Due to the large differences in resource endowment, economic development level, and institutional environment in different regions, the impact of ESG performance on corporate innovation may be different. Problems such as poor geography, a weak institutional environment, and underdeveloped economy are common in the central and western regions, which often lead to investors' withdrawal mentalities. ESG ratings can precisely change investors' original views of the central and western regions and increase their willingness to lend. On the contrary, the capital market development in the eastern region is more sound, and the role played by ESG ratings in the

[4] A more detailed description can be found at: http://www.dibdata.cn/.

Table 6B
Cross-sectional analysis: Industry characteristics.

Variables	(1)	(2)	(3)	(4)
	Patent1	*Patent1*	*Patent2*	*Patent2*
	High-pollution	Low-pollution	High-pollution	Low-pollution
ESG	0.124***	0.119***	0.061***	0.042***
	(7.14)	(9.37)	(5.25)	(5.10)
Size	0.506***	0.549***	0.188***	0.185***
	(16.96)	(24.99)	(12.65)	(15.44)
Lev	−0.188	−0.129	−0.175**	−0.224***
	(-1.43)	(-1.44)	(-2.31)	(-4.12)
Q	0.052***	0.074***	0.028***	0.027***
	(3.45)	(6.65)	(3.01)	(3.74)
ROA	0.538**	0.236	0.181	−0.134
	(2.16)	(1.38)	(0.96)	(-0.97)
Estage	−0.319***	−0.116**	−0.111**	−0.047
	(-3.50)	(-1.98)	(-2.40)	(-1.58)
Top1	0.001	−0.002	−0.001	−0.002***
	(0.40)	(-1.48)	(-0.75)	(-3.33)
SOE	0.032	0.198***	−0.045	0.020
	(0.49)	(4.49)	(-1.32)	(0.92)
Board	0.334**	0.093	0.172**	0.065
	(2.10)	(0.75)	(2.10)	(1.04)
Indep	0.002	0.000	−0.003	−0.001
	(0.33)	(0.03)	(-1.04)	(-0.75)
Pay	0.161***	0.161***	0.035*	0.050***
	(4.20)	(5.51)	(1.68)	(3.14)
Constant	−12.301***	−13.160***	−3.861***	−3.869***
	(-15.00)	(-22.02)	(-9.76)	(-12.96)
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
N	11,451	23,118	11,451	23,118
R^2	0.269	0.290	0.055	0.048
Between-group diff.	0.005**		0.018***	

Note: Variable definitions are shown in Table 2. T statistics are in parentheses and the standard errors are clustered at the firm level. ***, **, * denote significance at the 1%, 5%, and 10% levels, respectively.

eastern region is limited compared with that in the central and western regions.

To empirically test the conjectures, we divide the sample into an eastern region group and a central and western region group according to the province where the firms are located,[5] and the grouped regression results are shown in Table 6A. We can see that the coefficients of *ESG* are all significantly positive at the 1% level. However, the coefficients of *ESG* in the central and western region group is generally higher than the coefficients of *ESG* in the eastern region group. In addition, the difference in coefficients between groups is significant at the 5% and 1% levels. The results thus suggest that the positive impact of ESG performance on corporate innovation is more pronounced in the central and western regions.

5.2.2. The effect of industry characteristics

Considering that there are differences in pollution levels across industries, we further explore the heterogeneous impact of ESG performance on corporate innovation by subdividing the industries. First, investors pay more attention to heavily polluting industries while demanding a higher return on investment, which exacerbates the financing constraints faced by firms [70]. However, ESG ratings reduce compliance costs in heavy polluting industries in terms of disclosure, etc., and improved ESG performance enhances investor confidence in the sustainability of heavy polluting firms, which alleviates corporate innovation liquidity constraints to some extent. On the contrary, weakly polluting industries face weaker external regulation and lower compliance costs, and the mitigating effect of ESG ratings on financing constraints is more limited. In summary, the positive impact of ESG performance on corporate innovation is more significant in heavily polluting industries than in weakly polluting industries.

According to the *Guidelines for Environmental Information Disclosure of Listed Companies* issued by the Ministry of Environmental Protection in 2010, we group industries closely related to thermal power, cement, chemicals, and paper-making into the heavy pollution industry group and others into the low pollution industry group. The results of the subgroup regressions are shown in Table 6B. Columns (1) and (3) are for the heavy pollution industry group, and columns (2) and (4) are for the low pollution industry group. We can find that the coefficients of *ESG* are all significantly positive at the 1% level, but the coefficients of *ESG* in the heavy

[5] The eastern regions include Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Liaoning, Guangdong, and Hainan. The central regions include Shanxi, Anhui, Jiangxi, Henan, Jilin, Heilongjiang, Hubei, and Hunan. The western regions include Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang.

Table 7A
Robustness checks: Heckman two-stage model.

Variables	(1)	(2)	(3)
	ESG_m	Patent1	Patent2
ESG		0.118***	0.047***
		(11.42)	(6.87)
IV_ESG	0.559***		
	(15.06)		
IMR		−0.437***	−0.242***
		(-3.10)	(-2.98)
Size	0.223***	0.465***	0.147***
	(24.42)	(15.75)	(9.01)
Lev	−1.066***	0.194	−0.018
	(-21.42)	(1.40)	(-0.22)
Q	−0.063***	0.090***	0.041***
	(-9.03)	(7.79)	(5.50)
ROA	2.361***	−0.507*	−0.529***
	(16.54)	(-1.68)	(-2.77)
Estage	−0.171***	−0.115**	−0.033
	(-6.77)	(-2.16)	(-1.18)
Top1	0.002***	−0.001	−0.002***
	(2.99)	(-1.45)	(-3.60)
SOE	0.127***	0.103***	−0.023
	(6.76)	(2.64)	(-1.16)
Board	0.227***	0.106	0.065
	(4.24)	(1.05)	(1.25)
Indep	0.025***	−0.007*	−0.006***
	(15.47)	(-1.77)	(-2.88)
Pay	0.077***	0.137***	0.030**
	(5.73)	(5.49)	(2.18)
Constant	−9.511***	−10.358***	−2.448***
	(-31.37)	(-10.50)	(-4.55)
Year FE	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes
N	34,563	34,563	34,563
Pseudo R^2/R^2	0.092	0.282	0.050

Note: Variable definitions are shown in Table 2. T statistics are in parentheses and the standard errors are clustered at the firm level. ***, **, * denote significance at the 1%, 5%, and 10% levels, respectively.

pollution industry group are larger than the coefficients of *ESG* in the low pollution industry group. In addition, the difference in coefficients between groups is significant at the 5% and 1% levels. The above results are consistent with the expectation, that is, the facilitating effect of ESG performance on corporate innovation is more pronounced in the heavy polluting industries.

6. Robustness checks

6.1. Heckman two-stage model

Considering that firms exhibiting strong ESG performance may face lower external regulation and financing constraints, they might be more inclined to engage in corporate innovation activities, introducing a potential sample self-selection problem. In this regard, we re-run the regression using the Heckman two-stage model. Following previous literature [71,72], we select the mean ESG score of other firms in the same year and industry (*ESG_Mean*) as an exogenous instrumental variable. This variable has little correlation with specific firms, and the ESG performance of other firms will not have a direct impact on the innovation output of this firm, which satisfies the requirements of correlation and exogeneity of instrumental variables.

In the first stage, the inverse Mills ratio (*IMR*) in Equation (4) is calculated using the Probit model regression. In the second stage, the Inverse Mills Ratio (*IMR*) calculated in the first stage is introduced into Equation (1) and regressed again. The following regression model is constructed for the first stage:

$$ESG\_m_{i,t} = \beta_0 + \beta_1 ESG\_Mean_{i,t} + \delta Controls_{i,t} + Year + Industry + \varepsilon_{i,t} \quad (4)$$

Table 7A reports the regression results of the Heckman two-stage model. Column (1) shows the regression results of the first stage. The estimated coefficient of *ESG_Mean* is significantly positive at the 1% level, which indicates that this instrumental variable has a positive impact on the ESG performance. Meanwhile, factors such as firm size (*Size*), financial leverage (*Lev*), and firm age (*Estage*) affect whether a firm is able to obtain a good ESG rating. Column (2) presents the results of the second-stage regression, where the estimated coefficients of both the quantity of corporate innovation (*Patent1*) and the quality of corporate innovation (*Patent2*) are significantly positive at the 1% level. The above results indicate that, after controlling for the effect of sample self-selection, the contribution of ESG performance to corporate innovation remains significant.

Table 7B
Robustness checks: Alternative measures of ESG.

Variables	(1)	(2)
	Patent1	Patent2
ESG_b	0.024***	0.007***
	(6.39)	(3.29)
Size	0.547***	0.153***
	(17.20)	(8.72)
Lev	−0.305*	−0.167*
	(-1.84)	(-1.77)
Q	0.021	0.033***
	(1.36)	(2.95)
ROA	0.995***	−0.080
	(3.09)	(-0.36)
Estage	−0.326***	−0.118**
	(-3.42)	(-2.41)
Top1	0.001	0.001
	(0.61)	(0.65)
SOE	0.273***	0.013
	(4.18)	(0.40)
Board	0.207	0.150*
	(1.31)	(1.80)
Indep	−0.001	−0.002
	(-0.18)	(-0.72)
Pay	0.146***	0.038*
	(3.49)	(1.73)
Constant	−12.784***	−3.104***
	(-15.04)	(-7.24)
Year FE	Yes	Yes
Industry FE	Yes	Yes
N	11,114	11,114
R^2	0.276	0.039

Note: The decrease in sample size in columns (1) and (2) is due to the data released by Bloomberg from 2011 and the missing values of the explanatory variable. Variable definitions are shown in Table 2. T statistics are in parentheses, and the standard errors are clustered at the firm level. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

6.2. Alternative measures of ESG

In order to exclude possible bias caused by variable measures, we use ESG ratings data provided by Bloomberg to replace the original independent variable by relying on past research [21,73,74] and re-estimating Equation (1). Table 7B reports the results of the above regression. In columns (1) and (2), the estimated coefficients of the quantity of corporate innovation (*Patent1*) and the quality of corporate innovation (*Patent2*) remain significantly positive at the 1% level, resembling the baseline results.

6.3. Lagged dependent variables

Since the transmission of the impact of ESG performance on corporate innovation may take some time and there is a truncation bias, we front-load *Patent1* and *Patent2* by one period and two periods and use Equation (1) to examine the impact of firms' ESG performance in year t on corporate innovation in year $t+1$ and the impact of firms' ESG performance in year t on corporate innovation in year $t+2$. The results are shown in Table 7C. We can find that the impact of ESG performance on corporate innovation is significantly positive at the 1% level, whether we front-load the corporate innovation indicator by one period or two periods, indicating that the findings of this paper are robust.

6.4. Firm-fixed effects model

In order to avoid the potential impact of firms' heterogeneity on corporate innovation, we further use the firm-fixed effects model to conduct the robustness test, and the regression results are shown in Table 7D. It can be seen that the coefficients of both *Patent1* and *Patent2* are significantly positive at the 1% level, indicating that firm characteristics that do not follow time cannot change the conclusion of the benchmark regression.

Table 7C
Robustness checks: Lagged dependent variables.

Variables	(1)	(2)	(3)	(4)
	F_Patent1	F_Patent2	F2_Patent1	F2_Patent2
ESG	0.116***	0.048***	0.116***	0.063***
	(10.54)	(6.34)	(9.69)	(7.71)
Size	0.533***	0.183***	0.523***	0.175***
	(27.95)	(17.57)	(25.50)	(15.36)
Lev	−0.140*	−0.198***	−0.180**	−0.205***
	(-1.76)	(-4.08)	(-2.10)	(-3.91)
Q	0.072***	0.023***	0.076***	0.019***
	(7.09)	(3.60)	(6.73)	(2.82)
ROA	1.173***	0.357***	1.421***	0.438***
	(7.38)	(2.84)	(7.90)	(3.04)
Estage	−0.210***	−0.063**	−0.231***	−0.057*
	(-3.95)	(-2.28)	(-4.09)	(-1.90)
Top1	−0.001	−0.002***	−0.001	−0.001**
	(-0.93)	(-2.58)	(-0.61)	(-2.08)
SOE	0.162***	−0.005	0.178***	−0.008
	(4.12)	(-0.24)	(4.27)	(-0.38)
Board	0.154	0.101*	0.185*	0.153***
	(1.48)	(1.87)	(1.67)	(2.62)
Indep	0.001	−0.002	0.002	−0.000
	(0.41)	(-0.93)	(0.58)	(-0.01)
Pay	0.161***	0.045***	0.169***	0.046***
	(6.41)	(3.25)	(6.29)	(3.01)
Constant	−12.712***	−3.801***	−12.589***	−3.840***
	(-24.53)	(-14.57)	(-22.87)	(-13.65)
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
N	29,600	29,600	25,780	25,780
R^2	0.277	0.049	0.263	0.048

Note: Variable definitions are shown in Table 2. T statistics are in parentheses and the standard errors are clustered at the firm level. ***, **, * denote significance at the 1%, 5%, and 10% levels, respectively.

7. Conclusion and implications

7.1. Conclusions

In the background of "how to realize sustainable development" has become a common issue in the international community, it is of great theoretical and practical significance to examine the impact and mechanisms of ESG performance on corporate innovation at the micro level. In light of this, we explore the impact of ESG performance on both the quantity and quality of innovation output, utilizing a sample of Chinese listed companies from 2009 to 2021. Our findings reveal a significant positive correlation between ESG performance and corporate innovation. The mechanism tests indicate that corporate innovation is promoted through three channels: mitigating agency problems, enhancing information disclosure, and improving internal corporate governance. Further analysis on heterogeneity shows that the positive impact of ESG performance on corporate innovation is more pronounced in the central and western regions, as well as among firms in heavily polluting industries.

7.2. Theoretical implications

The exploration of the innovation impact of ESG performance is grounded in stakeholder-related theory. This is not only enriches the theoretical landscape of research on the microeconomic consequences of ESG but also complements studies focus on factors influencing corporate innovation. According to Dass et al. [24], the fixed-effect adjustment performs better in correcting the truncation bias in the number of citations. It confirms the relationship between ESG performance and corporate innovation in previous studies using an improved measure of corporate innovation [20,22,23], providing new implications for future research on enriching the innovation effects of ESG.

Furthermore, this paper reveals the mechanisms by which ESG performance influences corporate innovation, considering three perspectives: agency problems, information disclosure, and internal corporate governance. The findings align with Tang [23] that better social responsibility performance can reduce agency problems and meet shareholders' interests in carrying out innovative activities. And the emergence of ESG ratings is also shown to incentivize firms to improve information transparency, strengthen internal corporate governance, and actively utilize corporate innovation to achieve sustainable development.

This study also contributes to the literature by enriching heterogeneity factors of the impact of ESG performance on corporate innovation in emerging markets. Scholars have analyzed the factors like institutional investors' attention, executive characteristics, regional financial development, and industrial structure in relation to corporate innovation [22,23]. This article clarifies that relatively

Table 7D
Robustness checks: Firm-fixed effects model.

Variables	(1)	(2)	(3)	(4)
	Patent1	Patent2	Patent1	Patent2
ESG	0.080***	0.045***	0.053***	0.032***
	(10.73)	(6.03)	(7.31)	(4.27)
Size			0.431***	0.225***
			(18.83)	(13.11)
Lev			−0.068	−0.155**
			(-1.02)	(-2.54)
Q			0.019***	0.022***
			(3.04)	(3.22)
ROA			0.122	−0.185
			(1.29)	(-1.61)
Estage			0.456***	0.259**
			(3.74)	(2.45)
Top1			−0.001	−0.002
			(-0.51)	(-1.64)
SOE			−0.032	0.047
			(-0.66)	(0.97)
Board			0.182**	0.093
			(2.20)	(1.24)
Indep			0.001	0.002
			(0.29)	(0.88)
Pay			0.006	−0.017
			(0.34)	(-0.90)
Constant	1.442***	0.783***	−9.790***	−4.853***
	(47.16)	(25.97)	(-15.26)	(-9.41)
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
N	34,081	34,081	34,081	34,081
R^2	0.007	0.002	0.069	0.012

Note: Variable definitions are shown in Table 2. T statistics are in parentheses and the standard errors are clustered at the firm level. ***, **, * denote significance at the 1%, 5%, and 10% levels, respectively.

underdeveloped regions as well as heavily polluting industries strengthen the link between ESG performance and corporate innovation.

7.3. Practical implications

In the context of growing emphasis on sustainability requirements from governments, media, and other organizations, the ESG performance has a non-negligible impact on business operations. Here, we provide some policy implications.

First, firms are advised to strengthen ESG practices and balance corporate innovation with social and environmental responsibilities. Establishing reasonable ESG performance targets aligned with business characteristics and the operating environment can facilitate the achievement of environmental, social, and governance goals through strategic investment strategies. It is crucial for firms to develop a robust innovation management system, including the construction of an innovation culture, the training of innovation talents, efficient innovation project management, and the protection of intellectual property rights. By strengthening corporate governance, firms can integrate ESG factors into their products and services to meet market demand and enhance corporate value. In addition, seeking support and cooperation from stakeholders, such as government departments, industry associations, and research organizations, while continuously gathering stakeholder feedback, ensures that ESG performance yields a more substantial impact on innovation.

Second, regulators should not only strengthen the supervision of the quality of corporate ESG disclosure information but also employ market-oriented mechanisms to encourage firms to pay attention to ESG performance. In emerging markets, where ESG practices are not yet widely adopted, and the enthusiasm for ESG investments needs reinforcement, several measures can be implemented. On one hand, enhancing the authority of rating agencies can be achieved through the continual improvement of information disclosure systems and industry supervision. These measures are instrumental in boosting investors' confidence in their investment decisions. On the other hand, regulators can cooperate with financial institutions to provide incentives for firms exhibiting superior ESG performance or lagging behind. This may involve initiatives like issuing green bonds, offering subsidies, and implementing tax breaks to alleviate resource constraints faced by these firms. These efforts can improve the efficiency of resource allocation for firms and capital markets and stimulate the innovative vitality of ESG.

8. Limitations and further research

This paper still has some limitations and requires further discussion in the future.

First, a higher ESG rating does not necessarily equate to superior ESG performance. The reason for this is the various evaluation criteria among different rating agencies and the existence of "greenwashing" behavior.[6] The future development of ESG ratings faces certain challenges in standardizing indicator selection and exploring more multidimensional and specific ESG rating. Subsequent research could investigate the economic consequences based on improved ESG ratings. Second, in addition to financial constraints, agency problems, information disclosure, and internal corporate governance, there may be other potential mechanisms for future discussion, such as investor confidence and public attention. Third, the sample in this paper is listed companies in China. In the future, it would be interesting to study the relationship between ESG performance and corporate innovation in developed and developing countries at the industry level.

Data availability statement

Data will be made available on request.

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CRediT authorship contribution statement

Yan Wang: Writing – review & editing, Writing – original draft, Validation, Software, Project administration, Formal analysis, Data curation. **Xueke Wang:** Resources.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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