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Research article

Quantity and quality: The impact of environmental, social, and governance (ESG) performance on corporate green innovation

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ABSTRACT

Despite increasing attention to the economic consequences of environmental, social, and governance (ESG) performance, its impact on the quantity and quality of corporate green innovation (GI) remains underexplored. This study aims to reveal the impact and underlying mechanisms of ESG performance on corporate GI using a panel dataset of Chinese-listed enterprises. Our results show that ESG performance increases the quantity and quality of corporate GI by 2.72% and 3.20%, respectively. These significant positive effects are consistent across three ESG sub-ratings and a series of robustness tests, such as the instrumental variable (IV) test based on Confucian culture intensity. Mechanism analysis reveals that ESG performance positively affects corporate GI through the resource effect, governance effect, and innovation effect. Additionally, the GI impact of ESG performance is more pronounced in large, young, growing, and mature enterprises, enterprises in clean and low-carbon industries, and those located in key environmental protection (KEP) and two control zones (TCZ) cities. Our evidence provides insights into the informal drivers of corporate GI and the micro-GI effectiveness of ESG performance in emerging markets like China.

1. Introduction

As public environmental awareness grows, escalating environmental issues, such as climate change (Carlson et al., 2022), eco-destruction (Magalhães et al., 2023), and resource depletion (Scanlon et al., 2023), have captured global attention, calling for an accelerated transition to green and sustainable development (Shang et al., 2023). Green innovation (GI) can play a pivotal role in balancing economic growth and environmental protection, making it widely regarded as an essential driver for sustainable development (Umar and Safi, 2023). There is considerable focus on improving corporate GI performance to drive sustainable development since enterprises are major market players. While the literature has well elucidated the factors affecting enterprises' GI performance (Li et al., 2023c; Wen et al., 2023), there is still insufficient attention devoted to the impact of environmental, social, and governance (ESG) performance, a micro-sustainability assessment tool, on corporate GI. Particularly with potential concerns about growing greenwashing behavior (Xia et al., 2023) and patent bubbles (Wang et al., 2022), it is essential to further identify whether socially responsive enterprises are more likely to engage in GI activities, thereby improving the quantity and quality of their GI performance.

In this paper, we attempt to explore the potential link between ESG performance and corporate GI within the Chinese market across both quantity and quality dimensions. ESG performance has emerged as a crucial window for enterprises to signal their social responsibility to the market, thereby contributing to corporate green and sustainable development. It can also mitigate information asymmetry and transparent corporate sustainability efforts, consequently easing financial constraints for GI activities (Kim and Park, 2023; Zhang et al., 2023a). Beyond improving the information environment, ESG performance can tighten the collaborative networks between enterprises and stakeholders, thereby reducing agency costs (Wang et al., 2023a). Moreover, ESG performance can strengthen stakeholder accountability for corporate ESG practices, inducing enterprises to pursue green transformation for legitimacy. Against this background, does ESG performance as an informal environmental tool improve corporate GI in China? If so, what are

Abbreviations: GI, Green innovation; ESG, Environmental social and governance; DID, Difference-in-differences; OLS, Ordinary least squares; PSM, Propensity score matching; TWFE, Two-way fixed effects; IV, Instrumental variable; HDI, Human Development Index; KEP, Key environmental protection; TCZ, Two control zones; R&D, Research and development; GPRD, Green Patent Research Database; CNRDS, Chinese Research Data Services; CSMAR, China Stock Market and Accounting Research; CFCN, Confucian Culture Database; OI, Operating income

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the underlying mediating mechanisms? To answer these questions, we approach this possible micro-GI impact from both quantity and quality lenses.

Our paper relates to the literature on the relationship between ESG performance and GI. Despite the growing interest in this literature, extant studies on the quantity and quality of corporate GI remain underexplored. A recent study shows a significant influence of ESG performance on GI across 37 countries from 1990 to 2019 (Long et al., 2023). Narrowing the focus to micro-level GI, many scholars find that ESG performance significantly increases the number of green patent applications and grants of Chinese-listed enterprises (Zhai et al., 2022; Wang et al., 2023a; Yang et al., 2023; Zheng et al., 2023). However, the extant literature largely overlooked the impact on GI quality. An exclusive focus on the GI quantity may lead to an inaccurate assessment of the micro-GI efficacy of ESG performance, particularly when there is limited substantive GI progress (Huang et al., 2022; Wang et al., 2022). Going further, Tan and Zhu (2022) confirm that SynTao Green Finance's ESG ratings positively relate to both the quantity and quality of corporate GI in China employing difference-in-differences (DID), ordinary least squares (OLS), and propensity score matching-DID (PSM-DID) methods. Nonetheless, their work suffers from potential endogeneity problems, ignores the micro-GI effectiveness of ESG sub-ratings, and fails to delve into how this influence varies across different green patent types.

This study proposed three improvements to fill the aforementioned gaps. First, we use the data published by Sino-Security Information Service to measure corporate ESG performance and employ a two-way fixed effects (TWFE) model. Sino-Security Information Service specializes in evaluating both overall and sub-ESG performance for Chinese-listed enterprises. The data from this institution benefits us in understanding ESG performance more comprehensively. Our TWFE model, controlling for enterprise- and year-fixed effects, is designed to capture the overall positive GI effects of ESG performance. This model also helps to estimate how corporate GI quantity and quality respond to ESG sub-ratings. Second, we take green invention patent data as an improved measurement of corporate GI quantity and quality. Green invention patents can more accurately reflect corporate GI performance in responding to environmental regulations (Cheng et al., 2023), compared with overall green patent data. For robustness, we consider alternative GI measures, including different patent types and patent citations across years. Third, we adopt both the instrumental variable (IV) and DID approaches to address potential endogeneity challenges. We instrument ESG performance by the number of Confucius temples within a 450 km (500 km) radius of each city and the Human Development Index (HDI). Our DID tests provide additional quasi-natural experiment evidence from SynTao Green Finance's ESG ratings.

Our paper draws several main findings. First, ESG performance contributes to the quantity and quality of corporate GI by 2.72% and 3.2%, respectively, implying that ESG performance is an important micro-GI driver. We then evaluate the GI effects from the ESG sub-ratings and find that environmental ratings, social ratings, and governance ratings all play a significant contributing role, with governance ratings (environmental ratings) being the primary driver of GI quantity (GI quality). Our baseline results remain robust to various additional sensitivity analyses, including the IV test constructed by Confucian culture intensity. Second, our mechanism analysis shows that the resource effect, governance effect, and innovation effect can serve as effective channels for ESG ratings to positively stimulate corporate GI. Third, these GI effects exhibit heterogeneity at the micro-enterprise, meso-industry, and macro-city levels, which are significant among large, young, growing, and mature enterprises, enterprises in clean and low-carbon industries, and those located in key environmental protection (KEP) and two control zones (TCZ) cities.

Our contributions lie in three ways. First, our study delivers new empirical insights into the GI drivers from the ESG dimension. Previous studies have extensively discussed the determinants of corporate GI, with formal environmental regulations attracting more attention than informal ones (Liu et al., 2023c; Xu et al., 2023b; Hong et al., 2024). China initially relied primarily on government and market forces and introduced a series of formal environmental tools to achieve pollution control and sustainable development. Many command- and market-based environmental regulations have indeed been confirmed to have a positive role in promoting corporate GI (Chen et al., 2022b; Cheng et al., 2023). Nevertheless, implementation gaps may undermine the effectiveness of these formal policies (Zhang et al., 2022a), coupled with micro-level problems such as greenwashing behavior and patent bubbles remaining to be eradicated. So informal environmental regulations are increasingly considered an important complement to traditional environmental governance (Wu et al., 2023). In particular, ESG ratings, as a special informal environmental tool, can deepen public and corporate awareness of sustainable development through the pressure-transfer mechanism. However, it remains understudied as to whether and how ESG performance promotes corporate GI. In this context, we propose that ESG performance can serve as an effective informal driver for the quantity and quality of corporate GI, thereby alleviating concerns about greenwashing behavior and patent bubbles. Our work departs from previous efforts that explore the micro-GI impact of formal environmental regulations and further enriches current literature on the determinants of corporate GI from ESG performance.

Second, our work complements the available literature on the economic efficacy of ESG performance, particularly for corporate GI. Prior literature holds two different opinions regarding the effectiveness of ESG performance. The first opinion, dominant in the literature, supports that ESG performance is beneficial. For instance, high ESG performance tends to be associated with reduced corporate risks (He et al., 2023; Zhang et al., 2023d), enhanced corporate governance (He et al., 2022), increased economic returns (Shanaev and Ghimire, 2022; Zhou et al., 2022; Sandberg et al., 2023), relieved financial costs (Andries and Sprincean, 2023; Kong, 2023), and improved GI performance (Broadstock et al., 2020; Long et al., 2023). In contrast, the second one holds that ESG performance is ineffective. For example, ESG ratings can induce institutional retrogression, mislead stakeholders, and even lead to increased costs and serious agency issues (Entine, 2003; Avetisyan and Hockerts, 2017; Zheng and Aishan, 2023). As a response, this paper documents new positive micro-GI effects of ESG performance which supports the former opinion. Closely related to our work, Tan and Zhu (2022) reveal the positive impact of SynTao Green Finance's ESG ratings on the quantity and quality of corporate GI, ignoring endogeneity problems, ESG sub-ratings, and green patent types. Consequently, our study further provides suggestive evidence that ESG ratings and associated sub-ratings exert positive effects on corporate GI quantity and quality. Our findings remain robust after mitigating potential endogeneity concerns with IV and DID strategies and considering various green patent types individually and jointly, thereby expanding the understanding of the micro-GI effectiveness of ESG performance.

Third, our article delivers credible evidence on the efficacy of China's ESG system and sheds light on ESG construction and green development in China and other emerging countries. Compared with mature ESG systems in developed countries, those in emerging economies like China are still in the rapid development stage. Hence, our work has twofold advantages. On the one hand, the positive micro-GI impact of ESG performance provides beneficial evidence for emerging countries to further improve the evaluation and disclosure system of ESG performance. On the other hand, our findings can serve as a policy reference for these countries to address environmental challenges and transition to green development. This is because environmental issues are currently a thorny problem for many developing countries. Our findings demonstrate that ESG performance can induce enterprises to shift from profit-oriented growth to sustainable development, providing a solution for achieving both environmental and economic benefits.

The rest of our work is structured below. Section 2 combs through the relevant literature, renders testable hypotheses on whether and how ESG performance affects corporate GI, and details our empirical methodology. Section 3 provides our baseline results and a list of robustness tests. Section 4 introduces additional discussion, mainly covering mechanism and heterogeneity analyses. Section 5 concludes this article and outlines policy recommendations and limitations.

2. Material and methods

2.1. Literature review

Corporate ESG performance has attracted considerable attention from researchers and policymakers as it increasingly evolves into a crucial tool for fostering green and sustainable development (Saharti et al., 2024). Our study is linked to three streams of literature: the determinants of corporate GI, the consequences of ESG performance, and the impact of ESG performance on corporate GI. The details are outlined below.

The first stream of literature concentrates on the determinants of corporate GI primarily from formal and informal environmental regulations. The former highlights whether and how command- and market-based environmental tools affect corporate GI behavior. Command-based environmental regulations, such as dual carbon policy (Hong et al., 2024), low-carbon city pilot policy (Liu et al., 2023a), and SO_2 reduction targets (Xu and Sheng, 2023) contribute to corporate GI improvements. As for market-based environmental tools, green credit policy (Chen et al., 2024) and green finance reform (Jia et al., 2023) can effectively promote corporate GI performance. In contrast, Wang et al. (2023b) identify that environmental protection tax is an inhibitor of enterprises' GI activities. Compared to formal environmental regulations, less attention has been paid to the role of informal environmental regulations in corporate GI. Recent studies reveal that new media environment (Li et al., 2023c), public attention (Zhou and Ding, 2023), and corporate environmental information disclosure (Lu and Li, 2023) significantly enhance corporate GI, whereas social dishonesty exerts a negative impact (Liu et al., 2023d). While burgeoning studies have explored corporate GI determinants from various environmental regulations, the potential role of corporate ESG performance as an informal environmental tool is poorly documented.

The second stream of literature assesses the consequences of ESG performance, with a primary emphasis on its economic benefits. Current studies extensively explore the impact of ESG performance on corporate financial matters. For example, ESG performance can effectively reduce debt costs (Apergis et al., 2022; Kong, 2023), alleviate financial risks (Fu et al., 2024), enhance financial performance (Chen et al., 2023b; Sandberg et al., 2023), and improve market value (Zhou et al., 2022). Meanwhile, an increasing body of evidence indicates that ESG performance contributes to optimizing corporate governance. High ESG performance tends to closely correlate with mitigated information asymmetry (Kim and Park, 2023), reduced managerial myopia (Zhang et al., 2023b), inhibited managerial misconduct (He et al., 2022), and lowered share price crash risk (Luo et al., 2023b). In addition, some scholars document that ESG performance can serve as a non-financial driver for innovation capability. ESG performance contributes to enhancing corporate innovation performance (Li et al., 2023a) and particularly fostering GI across countries and firms (Long et al., 2023; Zheng et al., 2023). Despite extensive literature evaluating the economic consequences of ESG performance, relatively few researches have addressed the micro-GI impact of ESG performance.

The third stream of literature explores how enterprises' GI behavior responds to their ESG performance, a subject highly pertinent to our study. As summarized in Table A in Appendix A, a growing literature suggests that ESG performance has a significant positive impact on corporate GI, with evidence predominantly derived from the Chinese market. We find the majority utilizes the green patent data and evaluates the positive impact of ESG performance on corporate GI quantity (Zhai et al., 2022; Wang et al., 2023a; Yang et al., 2023; Zheng et al., 2023). In contrast, less attention has been devoted to the impact of ESG performance on corporate GI quality. Drawing on green patent applications and related citations, Tan and Zhu (2022) employ a DID approach and demonstrate that SynTao Green Finance's ESG ratings significantly enhance both the quantity and quality of corporate GI from 2010 to 2018. Although their results are robust to OLS and PSM-DID estimations, the potential endogeneity remains unaddressed. So far, a few scholars have assessed the micro-GI effectiveness of ESG performance, with the most overlooking its impact on corporate GI quality and associated endogeneity issues.

Overall, prior literature plays a critical role in advancing our study and leaves some research gaps that warrant further exploration. The first stream of literature has paid insufficient attention to corporate ESG performance as an informal environmental tool, compared to that of formal environmental regulations. The second stream of literature provides limited evidence on the effectiveness of ESG performance on micro-level GI. The third stream of literature remains underexplored regarding the influence of ESG performance on both the quantity and quality of corporate GI, which particularly fails to address related endogeneity concerns. As a response, we employ a TWFE model with data on green invention patent applications and related citations to estimate the effects of ESG performance on both the quantity and quality of corporate GI from 2009 to 2021 in China. For robustness, we also employ both the IV and DID approaches to address potential endogeneity issues.

2.2. Hypothesis development

2.2.1. ESG performance and corporate GI

China places great importance on corporate GI and values it as a crucial driver for modernization and sustainable development. While corporate GI performance can potentially bring environmental and economic benefits (Zhang and Liu, 2022; Zhao et al., 2022), high GI costs often induce enterprises to resort to cheaper end-of-pipe treatments in response to environmental regulations (Wang et al., 2023a). In response, ESG performance, effective in assessing corporate sustainability performance and potential risks, can potentially stimulate the quantity and quality of corporate GI in the following three ways.

First, ESG performance reflects enterprises' sense of environmental responsibility, which can motivate them to engage in GI activities. ESG performance can motivate enterprises to prioritize green practices, induce them to strengthen GI efforts for improved capacity to address environmental issues, and thereby drive sustainable development. Such proactive environmental consciousness would prompt enterprises to move beyond end-of-pipe treatment and instead focus on source treatment with GI, which usually induces advancements in both the quantity and quality of GI. Second, seeking ESG performance builds enterprises a positive corporate image and strengthens the connections with stakeholders. Therefore, higher ESG performance brings more resources for enterprises' GI activities. Enterprises with better ESG performance tend to get more trust from the public, investors and employees, and in turn achieve virtuous growth (Zhai et al., 2022). Such trust can facilitate a friendly external and internal environment for enterprises' sustainable development and ensure the necessary support for enterprises to undertake GI from both quantity and quality perspectives. Third, ESG performance can facilitate the implementation of corporate GI activities by reducing corporate risks (Chen et al., 2022a; Reber et al., 2022). The extant literature shows that proactively fulfilling social responsibility helps enterprises decrease negative impacts under potential environmental and social pressures (Do, 2022; Hsu and Chen, 2023). Similarly, ESG practices can effectively enhance enterprises' governance quality and pollution control capacity, thereby reducing their economic and

environmental risks. In this case, corporate GI risks should be reduced accordingly, so that enterprises can smoothly implement their GI strategies of quality and quantity, and thus improve their long-term competitiveness. Taken together, we suppose ESG performance can promote corporate GI efforts and propose Hypothesis 1 as follows:

Hypothesis 1. ESG performance can significantly promote corporate GI, which can be reflected in both quantity and quality dimensions.

2.2.2. Mechanism of ESG performance on corporate GI

If ESG performance positively impacts corporate GI, further investigation is needed to reveal the underlying mechanism behind this relationship. As displayed in Fig. 1, we discuss below whether the resource effect, governance effect, and innovation effect drive the expected micro-GI growth due to ESG performance.

First, ESG performance can effectively alleviate financial constraints and thereby promote corporate GI, which is called the resource effect. Based on signaling theory, ESG disclosure can enhance the transparency of corporate information and facilitate investors' access to corporate ESG performance, thus reducing information asymmetry between enterprises and investors. Corporate ESG achievements can reshape enterprises' responsible and sustainable image, thereby contributing to their financial and brand performance (Cowan and Guzman, 2020; Chen and Xie, 2022; Lee et al., 2022). Investors may tend to prioritize enterprises with high ESG ratings as trustworthy and valuable as public environmental awareness increases. Indeed, ESG performance and investors' ESG preferences are proven to be positively correlated with investment returns (Ling et al., 2023). This in turn can reduce investors' information-seeking costs and the adverse selection risks, thereby easing enterprises' financial constraints and benefiting their GI activities. Conversely, enterprises with poor ESG performance may fail to secure sufficient resources for corporate GI. This is primarily due to their tendency to be perceived as high-risk and socially irresponsible, making it difficult to obtain cost-effective funding from investors and lending institutions (Apergis et al., 2022). Given that ESG performance may promote corporate GI by resource effect from alleviating financial constraints, we propose Hypothesis 2 as follows:

Hypothesis 2. ESG performance can significantly improve corporate GI through the resource effect.

Second, ESG performance can effectively reduce agency costs and thus propel corporate GI, which is referred to as the governance effect. Agency theory holds that managers may prioritize corporate short-term interests over long-term benefits, leading to ineffective investments or even avoidance of innovation activities (Jensen and Meckling, 1976; Gao et al., 2022). ESG disclosure can generally mirror corporate ESG achievements. Previous literature implies that ESG disclosure can further break down information barriers and reduce corporate agency costs (Garzon Jimenez and Zorio-Grima, 2021; Chen et al., 2023a). On the one hand, ESG performance can strengthen shareholders' supervision of corporate sustainable development, and in turn, reduce managers' moral hazard and short-term behavior. Long-term investors in particular are more concerned with corporate governance performance and long-term interests, which can be beneficial in reducing agency costs and fostering corporate GI efforts. Meanwhile, high ESG performance can increase shareholders' tolerance for short-term fluctuations in corporate performance. In addition, firms with high ESG performance can reduce managers' dismissal risks from innovation failures, as transparency can alleviate managers' career concerns (Zhong, 2018). This implicit contractual effect from ESG performance can mitigate agency conflicts by facilitating the alignment of managers' and shareholders' interests, thus enhancing managers' willingness to conduct GI. Therefore, we argue that ESG performance can facilitate corporate GI by reducing agency costs and develop Hypothesis 3 as follows:

Hypothesis 3. ESG performance can significantly improve corporate GI through the governance effect.

Third, ESG performance can effectively increase research and development (R&D) expenditure and in turn drive corporate GI, which is described as the innovation effect. Legitimacy theory argues that enterprises are expected to behave following social norms, values, and beliefs, and serious inconsistencies can expose them to adverse shocks (Suchman, 1995; Zhou et al., 2021). As enterprises strive for legitimacy, they may voluntarily disclose ESG information and enhance ESG performance to demonstrate their environmental commitment. Additionally, enterprises tend to take GI as a response to environmental legitimacy, as it can effectively bridge the gap between societal expectations and enterprises' environmental behavior (Tachizawa and Wong, 2015; Li et al., 2016; Zhou et al., 2021). Therefore, enterprises are likely to increase their corporate R&D expenditure to obtain legitimacy. On the one hand, increased GI inputs can help enterprises cope with local institutional pressures and thus avoid potential legal risks. On the other hand, legitimacy can benefit enterprises in accessing key resources (Li and Lu, 2020), such as government subsidies, bank green credits, and customer loyalty, so ESG performance would stimulate increased investments in GI activities. As ESG performance possibly stimulates corporate GI by increasing R&D expenditure, we formulate Hypothesis 4 as follows:

Hypothesis 4. ESG performance can significantly improve corporate GI through the innovation effect.

2.3. Methodology

2.3.1. Empirical framework

We leverage a TWFE model to investigate the impact of ESG performance on corporate GI activities following prior studies (Chen et al., 2023a). Our econometric model is designed as follows:

$$GI_{it} = \alpha + \beta ESG_{it} + \gamma Controls_{it} + \lambda_i + \eta_t + \varepsilon_{it} \quad (1)$$

where i and t denote enterprise and year, respectively; GI_{it} and ESG_{it} signify the GI performance and ESG performance of enterprise i in year t, respectively; $Controls_{it}$ refers to a list of micro-level control variables; λ_i and η_t represent enterprise- and year-fixed effects, correspondingly; ε_{it} reflects the random disturbance. In Eq. (1), the sign and significance of β document the net impact of ESG performance on corporate GI, which is key for us to test Hypothesis 1.

2.3.2. Data

We construct an enterprise-year panel dataset with Chinese Shanghai and Shenzhen A-shares listed enterprises between 2009 and 2021.[1] Specifically, green patent data that assess the quantity and quality of corporate GI are from the Green Patent Research Database (GPRD) in the Chinese Research Data Services (CNRDS) database. Meanwhile, ESG data that measure corporate ESG performance come from the Wind database. Other enterprise-level information involving control variables and channel variables is derived from the China Stock Market and Accounting Research (CSMAR) database. The number of Confucian temples and the HDI used in our IVs are sourced from the Confucian Culture Database (CFCN) of the CNRDS database and Human Development Reports, respectively.

To make our work more compelling, the aforementioned sample undergoes the following treatments: (1) Excluding samples from the financial and real estate industries; (2) Excluding enterprises marked with ST, ST*, and PT; (3) All continuous variables, except the GI data,[2] are winsorized by 1% for both upper and lower bounds to mitigate noise

[1] We summarize the data sources for our main variables in Table B in Appendix B.

[2] We do not trim the tails of the GI data due to their small upper and lower intervals after taking the Log.

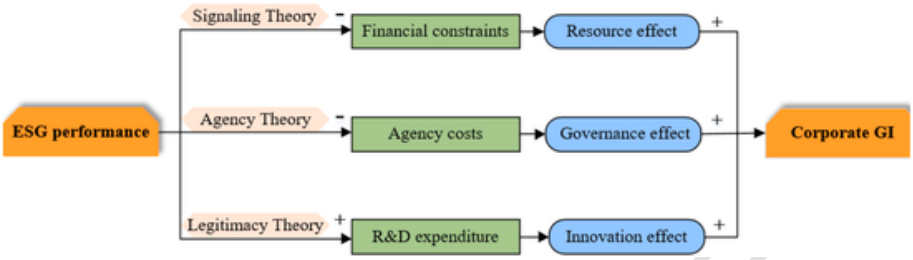

Fig. 1. Theoretical framework and supposed influence of ESG performance on corporate GI.

from extreme values; (4) Excluding null data that do not enter into our baseline regressions. Following this screening process, we ultimately obtain 27,603 enterprise-year observations from 2,879 listed enterprises.

2.3.3. Measures of GI

This paper measures the quantity and quality of corporate GI with green patent applications, which have been applied in many previous studies (Huang et al., 2022, 2023; Tan and Zhu, 2022). We take two measures to catch the dynamism of the patent data. Firstly, we take the Log of the sum of 1 and the number of green invention patent applications (*Log(1+IAN)*) to represent corporate GI quantity. This is mainly because applying for green patents is often challenging, making the application data a more appropriate measure than grant data. Secondly, we manually calculate the patent citations for green invention patent applications for the following five years due to the temporal variability of patent citation data. Similarly, we sum 1 with such data and then take the Log to form a proxy indicator (*Log(1+IAC)*) of the GI quality.

Fig. 2 depicts the trends in corporate GI quantity and quality from 2009 to 2021. The quantity and quality of GI are measured by the annual averages of *Log(1+IAN)* and *Log(1+IAC)*, respectively. The data on the quantity and quality of GI show the following two trends. First, the overall upward trend in the GI quantity and quality indicates that Chinese-listed enterprises have continued to make GI progress. This is consistent with the Chinese government's high emphasis on green and sustainable development as evidenced in previous studies (Liu et al., 2022; Zhu and Tan, 2022; Xu et al., 2023a). Second, there is a noticeable decline in corporate GI performance (both quantity and quality) in 2021. One possible reason is that the COVID-19 pandemic in 2020 induces enterprises to reduce their GI investments, and this cutback affects corporate GI outputs in 2021. Furthermore, the economic instability and uncertainty may make enterprises more cautious regarding GI as the global economy has yet to fully recover in 2021. In summary, despite a drop in 2021, corporate GI has experienced a general increase over the past decade as influenced by the government and the external environment.

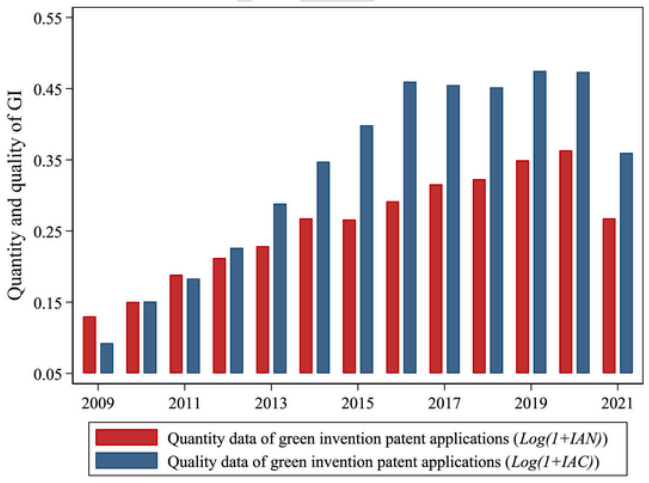

Fig. 2. Trends in the quantity and quality of GI from 2009 to 2021.

2.3.4. Measures of ESG performance

ESG performance, as the independent variable of our interest, is measured by ESG ratings from the Sino-Security Information Service (Luo et al., 2023a). This independent third-party ESG rating system is tailored to China's unique national conditions and capital market characteristics, covering all A-share listed enterprises in China. Such ESG ratings are mainly categorized into 9 grades: C, CC, CCC, B, BB, BBB, A, AA, and AAA. We assign each ESG rating with an integer value between 1 and 9 (Li et al., 2023b). We then use the average value of ESG ratings for each quarter of the year as a proxy variable for ESG performance. In addition, we adopt SynTao Green Finance's ESG rating data (Tan and Zhu, 2022) for the robustness test in Section 3.3.4.

Fig. 3 displays the distribution of ESG ratings for Chinese-listed enterprises in 2010, 2014, 2018, and 2021. We can draw three findings. First, the majority of corporate ESG ratings fall within the range of 3–5 and exhibit a bell-shaped curve. This indicates that quite a few enterprises have maintained a moderate ESG performance over the past few years, with very few outstanding performers. Second, the average corporate ESG ratings for 2010, 2014, 2018, and 2021 are 3.95, 4.04, 4.13, and 4.06, correspondingly. The changes in the average scores suggest that the overall ESG performance of Chinese-listed enterprises is on an upward trend until 2018, and then declines in 2021. Third, there are still many enterprises with low ESG ratings, implying significant room for improvement in corporate ESG performance.

2.3.5. Control variables

In line with earlier studies (Huang and Yang, 2021; Li et al., 2023a; Wang et al., 2023a), this paper controls for a range of enterprise characteristics that may affect corporate GI performance in Eq. (1). These control variables cover enterprises' operating conditions and governance structure. Specifically, the former takes into account the enterprise size (*Size*), leverage ratio (*Lev*), profitability (*ROA*), growth capacity (*Growth*), asset structure (*Fixed assets ratio*), cash holding (*Cash flow*), and enterprise age (*Log(Age)*). Besides, the latter includes whether the chairman and the managing director are the same person (*Duality*), the number of board directors (*Board*), the number of the supervisory board (*Supervisor*), the proportion of independent directors (*Independence*), and the degree of ownership concentration (*Holder*). Table 1 provides a summary of our main variables, including their definitions and descriptive statistics.

3. Results

3.1. Baseline results

Our work quantifies the average micro-GI effects of ESG performance for Hypothesis 1 in Eq. (1), with corresponding baseline results reported in Table 2. For robustness, we adopt enterprise-level clustered robust standard errors and control for both enterprise- and year-fixed

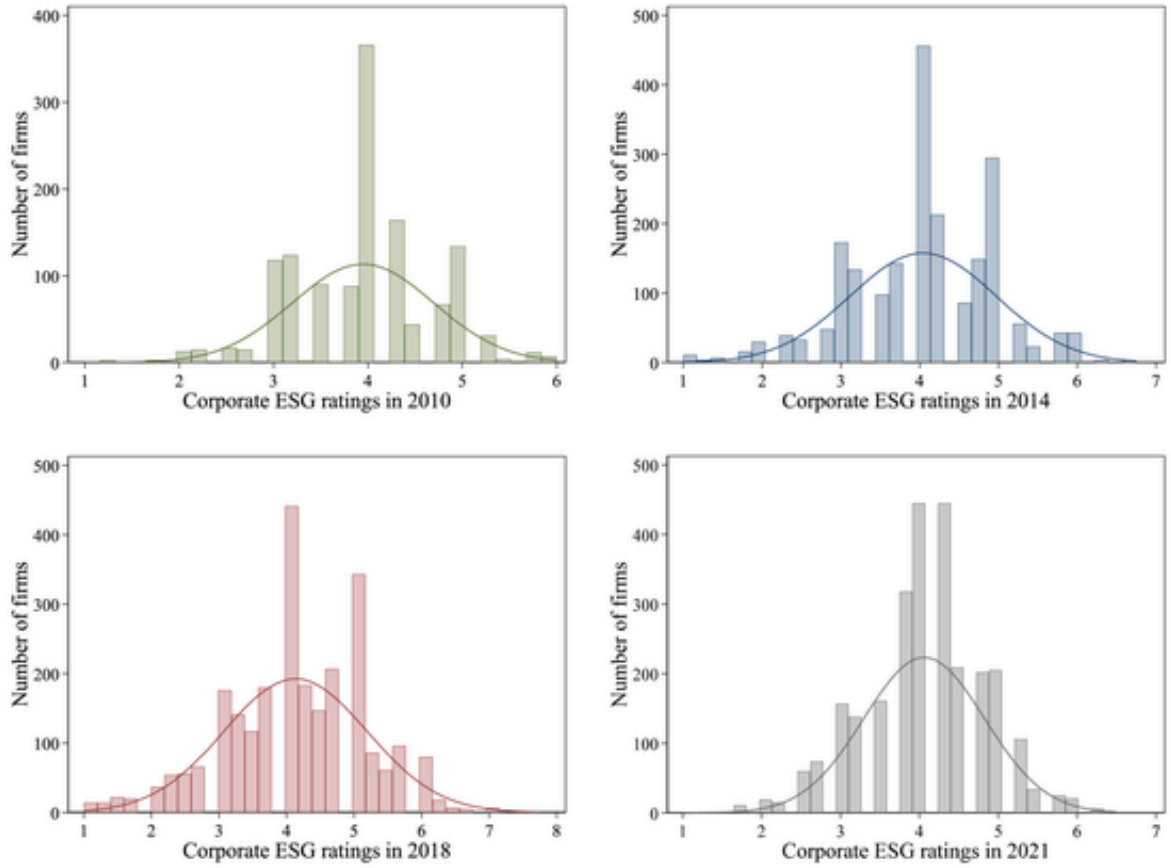

Fig. 3. Corporate ESG ratings distribution in 2010, 2014, 2018, and 2021.

effects. In Table 2, the outcome variable in columns (1)–(3) is the GI quantity calculated with *Log(1 + IAN)*, and that in columns (4)–(6) is GI quality represented by *Log(1 + IAC)*. We find that all the estimated coefficients of *ESG* on both the quantity and quality of GI in Table 2 are positively significant. As shown in columns (3) and (6), β in Eq. (1) is estimated as 0.0272 and 0.0320 with 1% statistical significance when *Log (1 + IAN)* and *Log(1 + IAC)* are taken as outcome variables, respectively. This suggests that ESG-rated enterprises would experience an average 2.72% and 3.20% increase in GI quantity and quality, respectively. Our results are positively significant regardless of whether enterprises' control variables are stepwise controlled. This result stability underscores the noteworthy role of ESG performance in driving both the quantity and quality of corporate GI, which echoes extant studies and validates Hypothesis 1 (Tan and Zhu, 2022; Wang et al., 2023a).

Our work preliminarily confirms the positive micro-GI effects of ESG performance across the Chinese market. Our findings deepen the understanding of the role of ESG ratings in facilitating corporate green transformation. Moreover, these results are particularly relevant to policymakers, investors, and enterprises seeking to make informed decisions and advance sustainable development.

3.2. The GI impact of the ESG sub-ratings

Since ESG performance consists of environmental, social, and governance ratings, we are interested in how these sub-ratings affect enterprises' GI performance. Similar to ESG rating data, we obtain environmental ratings (*E-score*), social ratings (*S-score*), and governance ratings (*G-score*) based on Sino-Security Information Service's ESG ratings, and subsequently use them to replace *ESG* in Eq. (1) for regressions. Table 3 reveals the effects of these three ESG sub-ratings on the quantity and quality of corporate GI, with *Log(1 + IAN)* and *Log(1 + IAC)* as outcome variables in columns (1)–(3) and (4)–(6), respectively. These coefficients of the *E-score*, *S-score* and *G-score* in columns (1)–(6) are all statistically positive with p-values less than 0.01, indicating that all three ESG sub-ratings can enhance both the quantity and quality of corporate GI. Governance ratings make the largest contribution to corporate GI quantity ($\bar{\beta} = 2.79\%$), while environmental ratings contribute the most to corporate GI quality ($\bar{\beta} = 4.16\%$). These findings unpack the internal structure of the positive GI effectiveness of ESG ratings and can enlighten enterprises to integrate their environmental, social, and governance efforts toward green development.

3.3. Robustness tests

3.3.1. Alterative patent types

To eliminate the possibility that GI measured by different patent types would lead to different results, our work employs green utility patent data in defining GI proxies (Li et al., 2022). Table 4 shows the regression results after considering other patent types. First, we construct *Log(1 + UAN)* and *Log(1 + UGN)* with the number of applications and grants for green utility model patents in columns (1) and (2), respectively, and find that *ESG* can significantly promote GI quantity. Second, we capture the significantly positive GI impact of ESG ratings by employing *Log(1 + TAN)* and *Log(1 + TGC)*, which are measured with the total number of green patent applications and grants in columns (3) and (4), respectively. Third, we adopt citation data on the number of green utility patent grants with and without self-citations over five years as GI quality indicators, i.e., *Log(1 + UGC)* and *Log(1 + UGC)*[d], in columns (5) and (6), respectively. The estimates for *ESG* in columns (5)–(6) both are 0.0166 and pass the 1% significance test, suggesting that ESG ratings

Table 1
Variables, definitions, and descriptive statistics.

Variable	Definition	Obs.	Mean	S.D.	Min	Max
Outcome variables						
Log(1 + IAN)	Log of "1 + the number of green invention patent applications each year"	27,603	0.27	0.69	0.00	6.75
Log(1 + IAC)	Log of "1 + the number of citations to green invention patent applications within five years"	27,603	0.36	0.88	0.00	7.27
Key independent variable						
ESG	ESG ratings averaged over four quarters per year	27,603	4.06	0.98	1.00	8.00
Control variables						
Size	Log of total assets	27,603	22.20	1.27	19.20	25.95
Lev	The total liabilities are divided by the total assets	27,603	0.43	0.20	0.05	0.88
Roa	The net profit divided by the average total assets	27,603	0.04	0.06	−0.25	0.21
Growth	The operating income divided by the previous year's operating income	27,603	0.17	0.39	−0.54	2.44
Fixed assets ratio	The net fixed assets divided by total assets	27,603	0.23	0.16	0.00	0.71
Cash flow	The net cash flow from operating activities divided by total assets	27,603	0.05	0.07	−0.16	0.25
Log(Age)	Log of the enterprise's age since it was established	27,603	2.86	0.35	1.61	3.50
Duality	= 1 if the chairman of the board and the managing director are the same person; = 0 otherwise	27,603	0.26	0.44	0.00	1.00
Board	Log of the number of board directors	27,603	2.14	0.20	1.61	2.71
Supervisor	Log of the number of directors on the supervisory board	27,603	1.24	0.25	0.69	1.95
Independence	The number of independent directors divided by that of board directors	27,603	0.37	0.05	0.30	0.57
Holder	Percentage of shares held by top ten shareholders (%)	27,603	57.12	15.20	22.81	95.80
Channel variables						
Financial constraints	The absolute value of the SA index	27,568	3.79	0.25	3.11	4.40
Agency costs	Management costs divided by operating income	26,223	0.09	0.07	0.01	0.42
R&D expenditure	R&D expenditure divided by total assets (%)	22,350	2.18	1.81	0.01	9.56
Instrumental variables						
Log (Contemple$_1$ + 1) × HDI	The interaction term between the log of "the number of Confucian temples within a 450 km radius of each city + 1" and the previous year's HDI	27,590	2.85	0.51	0.00	3.91
Log (Contemple$_2$ + 1) × HDI	The interaction term between the log of "the number of Confucian temples within a 500 km radius of each city + 1" and the previous year's HDI	27,590	2.98	0.51	0.47	3.98

can drive GI quality when other patent types are considered. Hence, leveraging other patent types to describe corporate GI performance does not affect our baseline findings, which is consistent with Hypothesis 1.

3.3.2. Alternative measures of GI quality

Using patent citations within different years to measure corporate GI quality may lead to different estimates. Following Cheng et al. (2023), we employ citation data over three and four years to avoid the potential bias from a single measure of GI quality. Specifically, we utilize citation data for green invention patent applications and grants over three years and four years as alternative measures of GI quality, respectively. For robustness, we additionally consider whether or not the outcome variables contain self-citations, with the superscript $_d$ to mark ones that exclude self-citations. Table 5 exhibits the estimation results with alternative outcome variables of GI quality. All estimates in columns (1)–(8) are statistically positive with p-values less than 0.01, fluctuating within the interval of $[0.0149, 0.0299]$. This suggests that enterprises' GI quality continues to exhibit a positive causal relationship with ESG performance, even after flexibly alternating the patent citations within different years.

3.3.3. Instrumented analysis

Potential endogeneity issues, such as the omission of unobservable variables, may lead to estimation bias and affect the validity of our evidence for Hypothesis 1. To address this challenge, our work refers to He et al. (2022) and Luo et al. (2023a), and employs an IV strategy constructed with Confucian culture intensity. In general, a well-designed IV should satisfy both correlation with the independent variable and exogeneity without directly affecting the dependent variable.

In this article, first, Confucian culture intensity has a positive correlation with corporate ESG performance. As pointed out by Cai et al. (2016), traditional cultural and ethical values can have a profound impact on enterprises' ESG behavior. The virtues of "benevolence" and "honesty" advocated by Confucian culture, the most influential culture in China, share similarities with the essence of ESG consensus, which can enhance the moral standard of enterprises. So the number of local Confucius temples, known as important places for disseminating Confucian culture, would positively correlate with corporate ESG performance. Second, Confucian culture intensity is exogenous to corporate GI performance. Confucian culture has been highly valued and developed in China for over 2,000 years and Confucius temples have been demanded in all states and countries since the Tang Dynasty. The distinctive historical character of Confucian cultural intensity certainly has no direct impact on corporate GI activities. Thus, our IV constructed with Confucian cultural intensity meets the prerequisites of correlation and exogeneity.

Considering that local Confucian temple quantity is not time-varying, we additionally collect the previous year's HDI to make our IV test more appropriate. Specifically, we employ the number of Confucius temples within a 450 km (500 km) radius of each city together with HDI to construct $Log(Contemple_1 + 1) \times HDI$ and $Log(Contemple_2 + 1) \times HDI$ for analysis, respectively. Table 6 documents the instrumented results estimated by the two-stage least square method. Columns (1) and (4) show a significant positive relationship between our IVs and *ESG* in the 1st stage. In the 2nd stage, we discover that the ESG performance continues to significantly increase both the quantity and quality of enterprises' GI. In summary, our results from Table 6 demonstrate that potential endogenous problems do not pose serious threats to our core findings, which corresponds to our expectations.

3.3.4. Quasi-natural experiment evidence from SynTao green Finance's ESG ratings

To address potential endogeneity issues, we refer to earlier studies (Wang et al., 2023a) and adopt SynTao Green Finance's ESG ratings as a quasi-natural experiment to estimate the micro-GI effects of ESG performance. Similar to ESG ratings from Sino-Security Information Service, those from SynTao Green Finance can not only match our enterprise sample but also prevent enterprises' manipulation. SynTao Green Finance began publicly evaluating the ESG performance of listed enter-

Table 2
The impact of the ESG ratings on the quantity and quality of corporate GI.

	Log (1 + IAN)			Log (1 + IAC)		
	(1)	(2)	(3)	(4)	(5)	(6)
ESG	0.0295***	0.0272***	0.0272***	0.0305***	0.0319***	0.0320***
	(0.0055)	(0.0055)	(0.0055)	(0.0073)	(0.0073)	(0.0073)
Size		0.0386***	0.0405***		0.0641***	0.0731***
		(0.0109)	(0.0114)		(0.0139)	(0.0146)
Lev		0.0377	0.0248		0.1837***	0.1400***
		(0.0368)	(0.0369)		(0.0510)	(0.0507)
Roa		0.1174*	0.1293**		−0.0587	−0.0182
		(0.0603)	(0.0603)		(0.0751)	(0.0752)
Growth		−0.0240***	−0.0217***		−0.0445***	−0.0370***
		(0.0059)	(0.0060)		(0.0078)	(0.0077)
Fixed assets ratio		0.0423	0.0366		0.1823***	0.1635***
		(0.0466)	(0.0463)		(0.0621)	(0.0614)
Cash flow		−0.0719	−0.0761		−0.0026	−0.0180
		(0.0493)	(0.0489)		(0.0665)	(0.0657)
Log(Age)		0.0617	0.0289		0.3465***	0.2326**
		(0.0778)	(0.0825)		(0.1011)	(0.1091)
Duality			−0.0079			−0.0225
			(0.0124)			(0.0163)
Board			0.0286			0.0208
			(0.0455)			(0.0665)
Supervisor			0.0410			0.0938*
			(0.0381)			(0.0489)
Independence			0.0433			0.1048
			(0.1400)			(0.1916)
Holder			−0.0010*			−0.0033***
			(0.0005)			(0.0008)
Constant	0.1530***	−0.8947***	−0.9072***	0.2379***	−2.2938***	−2.1511***
	(0.0223)	(0.3083)	(0.3352)	(0.0297)	(0.4027)	(0.4551)
Enterprise FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Obs.	27,603	27,603	27,603	27,603	27,603	27,603
R-squared	0.6955	0.6963	0.6964	0.7445	0.7474	0.7482

Notes: Standard errors in parentheses are clustered at the enterprise level. ***p < 0.01, **p < 0.05, *p < 0.1.

Table 3
The GI impact of ESG sub-ratings.

	Log (1 + IAN)			Log (1 + IAC)		
	(1)	(2)	(3)	(4)	(5)	(6)
E-score	0.0212***			0.0416***		
	(0.0066)			(0.0087)		
S-score		0.0244***			0.0310***	
		(0.0048)			(0.0062)	
G-score			0.0279***			0.0328***
			(0.0053)			(0.0070)
Enterprise controls	YES	YES	YES	YES	YES	YES
Enterprise FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Obs.	27,603	27,603	27,603	27,603	27,603	27,603
R-squared	0.6962	0.6964	0.6965	0.7486	0.7483	0.7483

Notes: Standard errors in parentheses are clustered at the enterprise level. ***p < 0.01, **p < 0.05, *p < 0.1.

prises on the CSI300 in 2015, and the number of covered enterprises is increasing as enterprises voluntarily disclose ESG information. Such data features provide convenience for us to adopt the DID method and establish equations as follows.

$$GI_{it} = \alpha + \beta ESG\_did_{it} + \gamma Controls_{it} + \lambda_i + \eta_t + \varepsilon_{it} \quad (2)$$

$$GI_{it} = \alpha + \beta ESG\_score_{it} + \gamma Controls_{it} + \lambda_i + \eta_t + \varepsilon_{it} \quad (3)$$

where ESG_did_{it} is a dummy variable, defined as 1 when SynTao Green Finance releases the ESG ratings of enterprise i in year t, and 0 otherwise; ESG_score_{it} is the intersection term of ESG_did_{it} and SynTao Green Finance's ESG scores. Particularly, SynTao Green Finance's ESG ratings are assigned with a similar rule as that for our key independent variable, i.e., assigning integers from 0 to 9 to D, C-, C, C+, B-, B, B+, A-, A, and A+ sequentially.

Table 7 summarizes the estimation results of SynTao Green Finance's ESG ratings on the quantity and quality of corporate GI, with columns (1)–(2) and (5)–(6) for Eq. (2), and columns (3)–(4) and (7)–(8) for Eq. (3). As shown in columns (1)–(8), all estimated coefficients of *ESG_did* and *ESG_score* are significantly greater than 0, with enterprise characteristics flexibly controlled in Eq. (2) and Eq. (3). This suggests that the quantity and quality of enterprises' GI grow in line with their ESG performance when taking SynTao Green Finance's ESG ratings as a policy shock. Accordingly, it is robust to conclude that ESG performance can positively affect both the quantity and quality of corporate GI.

Table 4
Considering other patent types.

	(1)	(2)	(3)	(4)	(5)	(6)
	Log(1 + UAN)	*Log(1 + UGN)*	*Log(1 + TAN)*	*Log(1 + TGC)*	*Log(1 + UGC)*	*Log(1 + UGC)*^{d}
ESG	0.0230***	0.0209***	0.0349***	0.0250***	0.0166***	0.0166***
	(0.0051)	(0.0051)	(0.0064)	(0.0056)	(0.0045)	(0.0043)
Enterprise controls	YES	YES	YES	YES	YES	YES
Enterprise FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Obs.	27,603	27,603	27,603	27,603	27,603	27,603
R-squared	0.6386	0.6418	0.7076	0.7074	0.6635	0.6321

Notes: *Log(1 + UAN)* represents the Log of "1 + the number of green utility model patent applications each year"; *Log(1 + UGN)* represents the Log of "1 + the number of green utility model patent grants each year"; *Log(1 + TAN)* represents the Log of "1 + the applications number of green invention patents and green utility model patents each year"; *Log(1 + TGC)* represents the Log of "1 + the grants number of green invention patents and green utility model patents each year"; *Log(1 + UGC)* represents the Log of "1 + the number of citations to green utility model patent grants within five years"; *Log(1 + UGC)*^{d} represents the Log of "1 + the number of citations without self-citations to green utility model patent grants within five years". Standard errors in parentheses are clustered at the enterprise level. ***p < 0.01, **p < 0.05, *p < 0.1.

Table 5
Alternative measures of GI quality.

	Within three years				Within four years			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Log(1 + IAC)	*Log(1 + IAC)*^{d}	*Log(1 + IGC)*	*Log(1 + IGC)*^{d}	*Log(1 + IAC)*	*Log(1 + IAC)*^{d}	*Log(1 + IGC)*	*Log(1 + IGC)*^{d}
ESG	0.0278***	0.0266***	0.0159***	0.0149***	0.0299***	0.0291***	0.0211***	0.0198***
	(0.0070)	(0.0069)	(0.0046)	(0.0043)	(0.0072)	(0.0071)	(0.0052)	(0.0050)
With Self-citations	YES	NO	YES	NO	YES	NO	YES	NO
Enterprise controls	YES	YES	YES	YES	YES	YES	YES	YES
Enterprise FE	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Obs.	27,603	27,603	27,603	27,603	27,603	27,603	27,603	27,603
R-squared	0.7135	0.7030	0.6130	0.6065	0.7329	0.7236	0.6579	0.6529

Notes: Similar to *Log(1 + IAC)*, *Log(1 + IGC)* is defined as Log of "1 + the number of citations to green invention patent grants within the given years". Standard errors in parentheses are clustered at the enterprise level. ***p < 0.01, **p < 0.05, *p < 0.1.

Table 6
Instrumented results.

	Model I			Model II		
	1st Stage	2nd Stage		1st Stage	2nd Stage	
	ESG	*Log(1 + IAN)*	*Log(1 + IAC)*	*ESG*	*Log(1 + IAN)*	*Log(1 + IAC)*
	(1)	(2)	(3)	(4)	(5)	(6)
ESG		0.4625*	0.9266**		0.4731*	0.9852**
		(0.2605)	(0.3979)		(0.2625)	(0.4079)
$Log(Contemple_1 + 1) \times HDI$	1.1518***					
	(0.4002)					
$Log(Contemple_2 + 1) \times HDI$				1.1389***		
				(0.3932)		
First-stage F-stat	8.282			8.390		
Enterprise controls	YES	YES	YES	YES	YES	YES
Enterprise FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Obs.	27,590	27,590	27,590	27,590	27,590	27,590
R-squared	0.5933	−0.5030	−1.5672	0.5933	−0.5279	−1.7813

Notes: The outcome variables in columns (1) and (4) are *ESG*, in columns (2) and (5) are *Log(1 + IAN)*, and in columns (3) and (6) are *Log(1 + IAC)*. The IVs for Model I and Model II are $Log(Contemple_1 + 1) \times HDI$ and $Log(Contemple_2 + 1) \times HDI$, respectively. Standard errors are reported in parentheses and clustered at the enterprise level. ***p < 0.01, **p < 0.05, *p < 0.1.

3.3.5. Other robustness tests

To further validate the positive role of ESG performance on corporate GI, this paper considers other possible factors that can contaminate our main findings and performs additional robustness checks as follows.

(1) Alternative measures of our key variables. Since different proxies for ESG performance and corporate GI may affect our judgment of Hypothesis 1, we flexibly employ alternative indicators for our key variables to verify the reliability of the baseline findings. Table 8 reports the estimation results with alternative measures for corporate GI and ESG performance. First, we assemble the green invention patent grant data and construct *Log(1 + IGN)* and *Log(1 + IGC)* as proxies for GI quantity and quality, respectively. As listed in columns (1)–(2), the coefficients of *ESG* on *Log(1 + IGN)* and *Log(1 + IGC)* are 0.0115 and 0.0244, respectively, with 1% statistical significance.

Table 7
Quasi-natural experiment evidence on the GI effects of ESG ratings.

	Log (1 + IAN)				Log (1 + IAC)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ESG_did	0.1505***	0.1427***			0.2581***	0.2480***		
	(0.0232)	(0.0236)			(0.0311)	(0.0313)		
ESG_score			0.0061***	0.0056***			0.0065***	0.0069***
			(0.0011)	(0.0011)			(0.0015)	(0.0015)
Enterprise controls	NO	YES	NO	YES	NO	YES	NO	YES
Enterprise FE	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Observations	27,603	27,603	27,603	27,603	27,603	27,603	27,603	27,603
R-squared	0.6972	0.6979	0.6956	0.6965	0.7483	0.7516	0.7445	0.7483

Notes: Standard errors in parentheses are clustered at the enterprise level. ***p < 0.01, **p < 0.05, *p < 0.1.

Table 8
Results of alternative measures.

	(1)	(2)	(3)	(4)	(5)	(6)
	Log(1+IGN)	*Log(1+IGC)*	*Log(1+IAN)*	*Log(1+IAC)*	$Log(1+IAN)_{t-1}$	$Log(1+IAC)_{t-1}$
ESG	0.0115***	0.0244***			0.0222***	0.0316***
	(0.0039)	(0.0057)			(0.0061)	(0.0076)
Log(ESG)			0.0774***	0.0852***		
			(0.0154)	(0.0213)		
Enterprise controls	YES	YES	YES	YES	YES	YES
Enterprise FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Obs.	27,603	27,603	27,603	27,603	24,131	24,131
R-squared	0.6493	0.6861	0.6963	0.7480	0.7081	0.7517

Notes: *Log(1+IGN)* denotes the Log of "1 + the number of green invention patent grants each year"; *Log(1+IGC)* denotes the Log of "1 + the number of citations to green invention patent grants within five years"; *Log(ESG)* denotes the Log of ESG ratings averaged over four quarters per year; $Log(1+IAN)_{t-1}$ and $Log(1+IAC)_{t-1}$ denote the one-period lag of *Log(1+IAN)* and *Log(1+IAC)*, respectively. Standard errors in parentheses are clustered at the enterprise level. ***p < 0.01, **p < 0.05, *p < 0.1.

Second, we take the Log form of *ESG* to measure ESG performance and find that ESG ratings remain positively correlated with GI quantity and quality in columns (3)–(4). Third, considering potential timing lags in the micro-GI impact of ESG performance, we lag *Log(1+IAN)* and *Log(1+IAC)* by one period to obtain $Log(1+IAN)_{t-1}$ and $Log(1+IAC)_{t-1}$, respectively. The estimated coefficients obtained in columns (5)–(6) indicate that the positive effects of ESG performance on corporate GI are largely unaffected. Overall, despite changing the measures of the key variables flexibly, our main results are not contaminated, and therefore Hypothesis 1 holds robustly.

(2) Adjusting the sample period for special events. Major economic-related events such as the 2015 Chinese "stock market crash" and the COVID-19 pandemic can potentially affect enterprises' GI efforts. It is therefore necessary to adjust the sample interval for a more accurate estimation. To achieve this, we exclude samples in 2015 and after 2019, and document the re-estimated results in columns (1)–(2) of Table 9. Obviously, Hypothesis 1 is further supported by the stable positive relationship between ESG performance and corporate GI.

(3) Excluding the enterprises located in municipalities. As municipalities are directly administered by the central government, their political resources and institutional levels are distinctively superior to those of ordinary prefecture-level cities. To avoid differences in administrative levels distorting our results, we rerun the baseline model after excluding enterprises located in Beijing, Tianjin, Shanghai, and Chongqing. The positive and significant coefficients in columns (3)–(4) of Table 9 are consistent with our baseline results, so Hypothesis 1 stands robustly.

(4) Controlling for province-year and industry-year fixed effects. Unobservable factors across provinces and industries probably

Table 9
Results with adjusted sample size and fixed effects.

	(1)	(2)	(3)	(4)	(5)	(6)
	Log(1+IAN)	*Log(1+IAC)*	*Log(1+IAN)*	*Log(1+IAC)*	*Log(1+IAN)*	*Log(1+IAC)*
ESG	0.0300***	0.0388***	0.0252***	0.0265***	0.0226***	0.0234***
	(0.0064)	(0.0087)	(0.0055)	(0.0078)	(0.0056)	(0.0073)
Enterprise controls	YES	YES	YES	YES	YES	YES
Province-Year FE	NO	NO	NO	NO	YES	YES
Industry-Year FE	NO	NO	NO	NO	YES	YES
Enterprise FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Obs.	20,099	20,099	23,353	23,353	27,539	27,539
R-squared	0.7186	0.7458	0.6777	0.7372	0.7152	0.7722

Notes: Standard errors in parentheses are clustered at the enterprise level. ***p < 0.01, **p < 0.05, *p < 0.1.

cause unexpected estimation biases in our work. For robustness, we jointly include province-year and industry-year fixed effects in Eq. (1) and present the regression results in columns (5)–(6) of Table 9. After controlling for additional fixed effects, the estimated coefficients on *ESG* remain significantly positive. Thus, our results are not threatened by the above factors and Hypothesis 1 continues to be valid.

4. Discussion

4.1. Mechanism analysis

Thus far, our work has provided robust evidence of the positive role of ESG ratings on corporate GI. However, it remains to be further verified whether the resource effect, governance effect, and innovation effect mentioned in Section 2.2.2 can serve as mediating mechanisms in this relationship. To test Hypothesis 2, we follow extant studies (Gao and Yuan, 2021; Zhang et al., 2022b, 2023c), adopt the mediation identification method of Baron and Kenny (1986) in combination with Eq. (1), and construct Eq. (4), Eq. (5) and Eq. (6) below.

$$GI_{it} = \alpha_1 + \beta ESG_{it} + \gamma_1 Controls_{it} + \lambda_i + \eta_t + \varepsilon_{it} \quad (4)$$

$$M_{it} = \alpha_2 + \varphi ESG_{it} + \gamma_2 Controls_{it} + \lambda_i + \eta_t + \varepsilon_{it} \quad (5)$$

$$GI_{it} = \alpha_3 + \beta' ESG_{it} + \vartheta M_{it} + \gamma_3 Controls_{it} + \lambda_i + \eta_t + \varepsilon_{it} \quad (6)$$

Where M_{it} represents the channel variables, namely *Financial constraints*, *Agency costs*, and *R&D expenditure*, through which ESG ratings can potentially impact enterprises' GI performance; $Controls_{it}$ stands for a collection of control variables.

4.1.1. Resource effect

As corporate innovation activities are often risky and costly, the ease of accessing resources can often affect an enterprise's innovation strategy. ESG performance, as critical non-financial information, enables enterprises to signal their green commitment to the market, gain trust from investors and creditors, and thereby mitigate financial constraints for GI activities (Luo et al., 2023a). Following prior literature (Hadlock and Pierce, 2010; Cheng et al., 2023), we take *Financial constraints*, the absolute value of the SA index,[3] as the channel variable for the resource effect. A high value of *Financial constraints* indicates that enterprises encounter challenges in obtaining financial support. Table 10 displays the estimated results for the resource effect. The results in columns (1) and (2)–(5) respectively demonstrate that ESG performance can effectively relieve enterprises' financial constraints, and then increase corporate GI with *Financial constraints* controlled. Accordingly, ESG performance can stimulate the quantity and quality of corporate GI through the resource effect, which is in line with Hypothesis 2.

4.1.2. Governance effect

ESG performance enables stakeholders to understand enterprises' ESG efforts, thereby urging enterprises to advance internal governance to realize green development. This can facilitate enterprises to control potential agency costs of corporate innovation activities, and thus secure enough resource support for GI activities. In this context, ESG ratings can enhance the governance effect by reducing agency costs, and thus contribute to corporate GI performance. Inspired by Zhang (2023), we adopt *Agency costs*, the ratio of management costs to operating income, as the channel variable for the governance effect. Table 11 presents the results of the governance effect. The results of columns (2) and (4), column (1), and columns (3) and (5) are obtained from the regressions of Eq. (4), Eq. (5), and Eq. (6), respectively. We can note that ESG ratings can greatly reduce enterprises' agency costs, thereby increasing the quantity and quality of corporate GI. Therefore, ESG performance can motivate enterprises to engage in GI through the governance effect, serving as compelling evidence for Hypothesis 3.

[3] SA index is calculated as $-0.737 \times assets + 0.043 \times assets^2 - 0.040 \times age$, where assets and age denote corporate assets and age, respectively.

Table 10
Estimation results for the resource effect.

	Financial constraints	Log (1 + IAN)	Log (1 + IAN)	Log (1 + IAC)	Log (1 + IAC)
	(1)	(2)	(3)	(4)	(5)
ESG	−0.0070***	0.0272***	0.0220***	0.0320***	0.0238***
	(0.0009)	(0.0055)	(0.0053)	(0.0073)	(0.0070)
Financial constraints			−0.7872***		−1.2038***
			(0.1416)		(0.1844)
Enterprise controls	YES	YES	YES	YES	YES
Enterprise FE	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES
Obs.	27,568	27,603	27,568	27,603	27,568
R-squared	0.9619	0.6964	0.6995	0.7482	0.7528

Notes: Standard errors in parentheses are clustered at the enterprise level. ***p < 0.01, **p < 0.05, *p < 0.1.

Table 11
Estimation results for the governance effect.

	Agency costs	Log (1 + IAN)	Log (1 + IAN)	Log (1 + IAC)	Log (1 + IAC)
	(1)	(2)	(3)	(4)	(5)
ESG	−0.0024***	0.0272***	0.0250***	0.0320***	0.0238***
	(0.0006)	(0.0055)	(0.0055)	(0.0073)	(0.0073)
Agency costs			−0.2252**		−0.4472***
			(0.0934)		(0.1216)
Enterprise controls	YES	YES	YES	YES	YES
Enterprise FE	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES
Obs.	26,217	27,603	26,217	27,603	26,217
R-squared	0.7497	0.6964	0.6971	0.7482	0.7586

Notes: Standard errors in parentheses are clustered at the enterprise level. ***p < 0.01, **p < 0.05, *p < 0.1.

4.1.3. Innovation effect

It is generally recognized that enterprises' innovation performance is inextricably linked to their upfront innovation inputs, especially R&D expenditure. If enterprises lack sufficient R&D expenditure to support their GI activities, they may struggle to achieve their GI strategies, hindering their progress toward green transformation. Our work leverages *R&D expenditure*, the percentage of R&D inputs to total assets (%), as the channel variable for the innovation effect. Table 12 reports the estimated results on whether ESG ratings can enhance corporate GI performance via the governance effect. All estimated coefficients for *ESG* and *R&D expenditure* in columns (1)–(5) are positively significant at the 1% level, suggesting that the governance effect is a qualified mediating mechanism. Enterprises with high ESG ratings tend to prioritize long-term growth and increase their R&D expenditure to quantitatively and qualitatively enhance GI competitiveness, thus proving Hypothesis 4.

4.2. Heterogeneous analysis

The above discussion has given plenty of evidence on whether and how ESG performance contributes to the quantity and quality of enterprises' GI. However, inspired by extant literature (Huang et al., 2022; Xu et al., 2023b), these positive micro-GI effects of ESG performance might depend on other factors at the enterprise-industry-city level. Therefore, we attempt to investigate whether such positive GI effects are heterogeneous amongst different enterprises, industries, and cities.

Table 12
Estimation results for the innovation effect.

	R&D expenditure	Log (1 + IAN)	Log (1 + IAN)	Log (1 + IAC)	Log (1 + IAC)
	(1)	(2)	(3)	(4)	(5)
ESG	0.0452***	0.0272***	0.0244***	0.0320***	0.0219***
	(0.0137)	(0.0055)	(0.0061)	(0.0073)	(0.0080)
R&D expenditure			0.0302***		0.0315***
			(0.0054)		(0.0075)
Enterprise controls	YES	YES	YES	YES	YES
Enterprise FE	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES
Obs.	22,300	27,603	22,300	27,603	22,300
R-squared	0.8148	0.6964	0.7041	0.7482	0.7660

Notes: Standard errors in parentheses are clustered at the enterprise level. ***p < 0.01, **p < 0.05, *p < 0.1.

4.2.1. Micro-enterprise heterogeneity

(1) Grouped by enterprise scale. Enterprise scale is recognized as a major factor in influencing corporate GI performance (Akcigit and Kerr, 2018; Liu et al., 2023b). Can enterprise scale deliver heterogeneous effects in the link between ESG performance and enterprises' GI? Accordingly, we sort enterprises into small- and large-scale groups based on their operating income (OI) in the lower and upper quartiles, respectively. Columns (1)–(4) of Table 13 illustrate the heterogeneous results based on the enterprise scale. We observe that the coefficients of *ESG* on *Log(1+IAN)* and *Log(1+IAC)* are both significantly positive in the large-scale group, whereas neither is significant in the small-scale group. Compared to small enterprises, large enterprises tend to possess greater resources and capabilities to drive GI, such as larger R&D budgets. Additionally, large enterprises may face great social and political scrutiny, which requires them to actively fulfill their social and environmental responsibilities to maintain their legitimacy. As a result, ESG performance can have a more pronounced impact on driving the quantity and quality of corporate GI in the large-scale group.

(2) Grouped by enterprise age. Enterprise age can exert an influence on corporate innovation performance (Barasa et al., 2017; Leyva-De la Hiz and Bolívar-Ramos, 2022). To explore the heterogeneity from enterprise age, we categorize the full sample into young and old groups according to the lower and upper quartiles of enterprise age, respectively. Enterprise age is calculated as follows: Age = "current year - the year the enterprise was established + 1". Columns (5)–(8) of Table 13 shows the results for young and old enterprises. The coefficients of *ESG* capture significant positive effects on the quantity and quality of GI among young enterprises, but not in old enterprises. A potential explanation is that old enterprises usually respond slowly to new challenges and are conservative in reshaping their GI strategies due to organizational inertia, resulting in insignificant GI effects. In contrast, young enterprises are more flexible to pursue riskier environmental opportunities, which is conducive to promoting GI activities.

(3) Grouped by enterprise life cycle. An enterprise's innovation behavior would change with its life cycle stage (Coad et al., 2016). Does the micro-GI impact of ESG performance vary with the enterprise life cycle? We refer to Dickinson (2011) and adopt cash flow patterns to represent the enterprise life cycle, which can eliminate the distraction of industry differences. Based on positive and negative net cash flows from operating, investing, and financing activities, we split the sample into four groups: initial stage, growth stage, maturity stage, and decline stage.

Table 14 reports the heterogeneous analysis based on the enterprise life cycle. We find that ESG performance can significantly increase the quantity and quality of GI at the 1% level for enterprises in growth and maturity stages, whilst failing to yield such a double significant impact in the initial stage. That can be explained that enterprises in growth and maturity stages can access abundant resources to support their GI activities as compared to those in initial stage. Columns (7) and (8) reveal that ESG ratings remain a significant contributor to GI quantity among enterprises in decline stage, but not for GI quality. This suggests that declining enterprises are reluctant to take on difficult and risky innovation activities, but they still strive to maintain their GI quantity performance.

4.2.2. Meso-industry heterogeneity

There is often a positive correlation between industry pollution and the environmental regulation intensity to which enterprises in that industry are subjected. Such diverse environmental pressure may affect the positive GI effects of ESG ratings. Therefore, we try to reveal the heterogeneity of such GI effects across samples with different industry pollution and industry carbon emissions.

(1) Grouped by industrial pollution. Following Fang et al. (2021) and Yao et al. (2021), we refer to an official document[4] issued in 2008 and assign the sample to which enterprises belong to clean and dirty industries. Columns (1)–(4) in Table 15 exhibit the heterogeneous effects of ESG performance on corporate GI across diverse industrial pollution. When taking *Log(1+IAN)* as the outcome variable, the estimated coefficient of *ESG* is significantly positive in column (1), but not in column (3). This may be because enterprises belonging to dirty industries are exposed to greater environmental burdens as compared to those belonging to clean ones, which adversely affect their GI quantity. In contrast, the estimated coefficients in columns (2) and (4) are significant with values of 0.0319 and 0.0278, respectively, when taking *Log(1+IAC)* as the outcome variable. This suggests that regardless of the industrial pollution intensity, ESG ratings can enhance enterprises' environmental awareness, thus improving their GI quality performance.

(2) Grouped by industrial carbon emissions. Referring to Hu et al. (2020), we classify our sample into low-carbon and high-carbon industries based on industrial carbon emissions. Columns (5)–(6) and (7)–(8) in Table 15 report the results. ESG ratings lead to a 2.88% increase in corporate GI quantity among low-carbon industries in column (5) but do not make a similar impact in high-carbon industries in column (7). This can be explained that high-carbon industries, compared to low-carbon industries, are subject to higher GI thresholds and require considerable resource inputs for R&D activities, resulting in insignificant growth in corporate GI quantity. Meanwhile, the results in columns (6) and (8) indicate that ESG ratings can significantly facilitate enterprises' GI quality in both low-carbon and high-carbon industries. The possible explanation is that ESG performance can enable enterprises to focus more on the development and application of green technologies, thereby improving GI quality in both low-carbon and high-carbon industries.

4.2.3. Macro-city heterogeneity

The importance cities place on environmental protection and sustainable development can affect the willingness of enterprises to voluntarily improve ESG performance and engage in GI activities. In this con-

[4] Further information can be found on the Chinese official website:https://www.gov.cn/gzdt/2008-07/07/content_1038083.htm.

Table 13
Heterogeneous analysis based on enterprise scale and enterprise age.

	Enterprise scale				Enterprise age			
	Log(1+IAN)	*Log(1+IAC)*	*Log(1+IAN)*	*Log(1+IAC)*	*Log(1+IAN)*	*Log(1+IAC)*	*Log(1+IAN)*	*Log(1+IAC)*
	Small	Small	Large	Large	Young	Young	Old	Old
	OI<25%	OI<25%	OI>75%	OI>75%	Age<25%	Age<25%	Age>75%	Age>75%
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ESG	0.0089	−0.0051	0.0247*	0.0423**	0.0292***	0.0523***	0.0058	−0.0044
	(0.0065)	(0.0103)	(0.0144)	(0.0171)	(0.0109)	(0.0160)	(0.0082)	(0.0097)
Enterprise controls	YES	YES	YES	YES	YES	YES	YES	YES
Enterprise FE	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Obs.	6,695	6,695	6,821	6,821	5,449	5,449	6,541	6,541
R-squared	0.6095	0.6904	0.7700	0.8054	0.7543	0.7899	0.7848	0.8734

Notes: Standard errors in parentheses are clustered at the enterprise level. ***p < 0.01, **p < 0.05, *p < 0.1.

Table 14
Heterogeneous analysis based on enterprise life cycle.

	Initial stage		Growth stage		Maturity stage		Decline stage	
	Log(1+IAN)	*Log(1+IAC)*	*Log(1+IAN)*	*Log(1+IAC)*	*Log(1+IAN)*	*Log(1+IAC)*	*Log(1+IAN)*	*Log(1+IAC)*
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ESG	0.0198	0.0135	0.0298***	0.0417***	0.0223***	0.0323***	0.0169*	0.0035
	(0.0173)	(0.0249)	(0.0108)	(0.0131)	(0.0086)	(0.0106)	(0.0092)	(0.0133)
Enterprise controls	YES	YES	YES	YES	YES	YES	YES	YES
Enterprise FE	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Obs.	2,641	2,641	8,219	8,219	9,838	9,838	4,563	4,563
R-squared	0.7470	0.7888	0.7387	0.7952	0.7514	0.7927	0.7789	0.8408

Notes: Standard errors in parentheses are clustered at the enterprise level. ***p < 0.01, **p < 0.05, *p < 0.1.

Table 15
Heterogeneous analysis based on industrial pollution and industrial carbon emissions.

	Industrial pollution				Industrial carbon emissions			
	Clean		Dirty		Low-carbon		High-carbon	
	Log(1+IAN)	*Log(1+IAC)*	*Log(1+IAN)*	*Log(1+IAC)*	*Log(1+IAN)*	*Log(1+IAC)*	*Log(1+IAN)*	*Log(1+IAC)*
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ESG	0.0343***	0.0319***	0.0133	0.0278***	0.0288***	0.0295***	0.0211	0.0265*
	(0.0071)	(0.0097)	(0.0089)	(0.0100)	(0.0060)	(0.0083)	(0.0141)	(0.0153)
Enterprise controls	YES	YES	YES	YES	YES	YES	YES	YES
Enterprise FE	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Obs.	18,876	18,876	8,675	8,675	22,363	22,363	5,203	5,203
R-squared	0.7095	0.7555	0.6685	0.7408	0.7224	0.7618	0.5813	0.6937

Notes: Standard errors in parentheses are clustered at the enterprise level. ***p < 0.01, **p < 0.05, *p < 0.1.

text, we attempt to explore the macro-city heterogeneity in the micro-GI effects of ESG performance from the lens of KEP and TCZ policies.

(1) KEP policy. During the 11th Five-Year Plan, China implemented the KEP policy in 113 cities to promote pollution control and environmental protection. We match the location of enterprises with these 113 cities and group our sample into KEP and non-KEP cities. The environmental regulation intensity in KEP cities is often stricter than that in non-KEP cities, which can promote environmental behavior among enterprises. Columns (1)–(4) in Table 16 show the micro-GI effects of ESG performance in KEP and non-KEP cities. ESG performance significantly drives the quantity and quality of corporate GI in KEP cities by 2.87% and 3.43%, respectively, while similar effects do not appear in non-KEP cities. It is possible that enterprises in KEP cities, compared with those in non-KEP cities, face greater pressure in environmental protection, making them pay more attention to ESG performance and GI activities.

(2) TCZ policy. China approved the implementation of the TCZ policy in 1998, which is designed to alleviate air pollution among acid rain and sulfur dioxide pollution control zones. Accordingly, we classify the sample into TCZ and non-TCZ cities based on whether the enterprise is located in TCZ cities to analyze possible heterogeneity. Columns (5) to (8) in Table 16 present the estimated heterogeneous effects of ESG performance on enterprises' GI across TCZ and non-TCZ cities. We find that ESG ratings can significantly facilitate the quantity and quality of corporate GI in TCZ cities. One possible reason is that the TCZ policy, as a formal environmental tool, can enable governments to strengthen corporate pollution control and even provide subsidies to support enterprises' GI activities. In contrast, the insignificant GI impact of ESG performance in non-TCZ cities is probably because of the local loose environmental regulations that provide enterprises with the flexibility to adopt environmental measures.

Table 16
Heterogeneous analysis based on KEP policy and TCZ policy.

	KEP policy				TCZ policy			
	Non-KEP cities		KEP cities		Non-TCZ cities		TCZ cities	
	Log(1+IAN)	*Log(1+IAC)*	*Log(1+IAN)*	*Log(1+IAC)*	*Log(1+IAN)*	*Log(1+IAC)*	*Log(1+IAN)*	*Log(1+IAC)*
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ESG	0.0161	0.0173	0.0287***	0.0343***	0.0120	0.0136	0.0288***	0.0343***
	(0.0135)	(0.0178)	(0.0060)	(0.0080)	(0.0139)	(0.0215)	(0.0060)	(0.0078)
Enterprise controls	YES	YES	YES	YES	YES	YES	YES	YES
Enterprise FE	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Obs.	3,777	3,777	23,813	23,813	3,502	3,502	24,095	24,095
R-squared	0.6234	0.6793	0.7031	0.7538	0.6564	0.6819	0.7010	0.7548

Notes: Standard errors in parentheses are clustered at the enterprise level. ***p < 0.01, **p < 0.05, *p < 0.1.

5. Conclusions

5.1. Conclusions

ESG performance reflects the corporate socially responsible commitment to sustainable development. However, are socially responsive enterprises more likely to conduct GI in terms of both quantity and quality? To respond to this question, our work employs a dataset of Chinese-listed enterprises from 2009 to 2021 and provides empirical evidence on the nexus and influence channels between ESG performance and corporate GI. We find that ESG performance plays a role in improving the quantity and quality of corporate GI by 2.72% and 3.20%, respectively. ESG sub-ratings, covering environmental ratings, social ratings, and governance ratings, exhibit similar positive GI effects. Such positive effects remain robust after undergoing several sensitivity exercises, in particular the IV test constructed with Confucian culture intensity. Moreover, our mechanism analysis indicates that ESG performance promotes corporate GI mainly through three channels: the resource effect from alleviating financial constraints, the governance effect from reducing agency costs, and the innovation effect from increasing R&D expenditure. Additionally, our enterprise-industry-city-level heterogeneous results reveal that ESG performance can more significantly drive the quantity and quality of corporate GI among large, young, growing, and mature enterprises, particularly for enterprises belonging to clean and low-carbon industries, and those located in KEP and TCZ cities.

5.2. Policy recommendations

Our work provides three suggestions for improving China's ESG construction and green development. First, enterprises need to prioritize the positive GI impact of ESG performance and enhance their ESG efforts to promote corporate green transformation and sustainable development. Our core findings suggest that ESG performance is effective in promoting the quantity and quality of corporate GI. It is therefore crucial for enterprises to incorporate ESG issues into their sustainability targets and foster systematic attention to improving ESG ratings and associated sub-ratings. Meanwhile, enterprises are suggested to provide ESG-related training to foster a conducive ESG culture, raise employees' ESG awareness, and optimize their ESG practices. This approach helps employees better understand ESG principles and consciously engage in and support corporate ESG initiatives, thereby driving green and sustainable development. In particular, enterprises are recommended to take targeted actions to enhance their ESG performance when advancing GI progress, recognizing the salient contribution of governance ratings (environmental ratings) to GI quantity (GI quality). Enterprises should be encouraged to improve their governance ratings for increased GI quantity, for example, by establishing robust structures and effective decision-making processes. Concurrently, reducing environmental impacts, and increasing environmental concerns could enhance corporate environmental ratings, thereby contributing to high-quality GI progress.

Second, policymakers need to introduce incentives to enhance the resource, governance, and innovation effects within enterprises, thereby strengthening the driving impact of ESG ratings on both the quantity and quality of corporate GI. On the one hand, the government could improve supportive financial mechanisms for enterprises, encouraging them to actively increase ESG and GI efforts. Governments can offer special GI funds and subsidies to enterprises with high ESG performance. Financial institutions could also be motivated to prioritize corporate ESG performance and incorporate it as a financing criterion. On the other hand, policymakers are suggested to appropriately refine the ESG disclosure requirements for enterprises, ensuring that stakeholders can access timely and transparent corporate sustainability performance. Implementing a standardized ESG disclosure framework can offer investors and the public reliable ESG information, benefit enterprises in reducing agency costs, and thus facilitate corporate GI activities. Furthermore, to boost the innovation effect of enterprises, policymakers can roll out additional preferential policies, such as tax subsidies. Intensified protection of intellectual property rights and improved technology-sharing networks are equally essential for enterprises to increase their innovation inputs, thereby fostering local sustainable development.

Third, the government needs to consider the specific attributes of enterprises, industries, and regions to enhance the positive micro-GI impact of ESG performance. According to our heterogeneity analysis, the positive impact of ESG performance on the quantity and quality of corporate GI is not significant among small, old, and start-up enterprises, as well as those located in non-KEP and non-TCZ cities. Therefore, the government can flexibly adjust the supporting measures for these groups to highlight their GI effects of ESG performance, including regulating ESG disclosures, reducing financial costs, and improving institutional environments. In particular, we find that ESG performance does not significantly affect corporate GI quality during the enterprise's decline stage. As such, the government could guide enterprises to regularly review and update their ESG targets, strengthen their communication with stakeholders, and thereby drive substantial and sustained progress in corporate GI. Meanwhile, ESG performance appears to contribute little to the GI quantity of enterprises belonging to dirty and high-carbon industries. To deepen their green transformation, local governments should develop differentiated GI support for these two industries, such as R&D funding, technology resources, and knowledge sharing.

5.3. Limitations

Our study is confronted with some limitations, which potentially provide avenues for future research. First, due to data limitations, our assessment of corporate GI quality relies solely on the citation data re-

lated to green patents. To better understand the impact of enterprises' ESG performance on corporate GI, future studies are warranted to assess corporate GI quality with more detailed green patent information or other comprehensive measures. Second, the lack of consensus on the definition and measurement of corporate ESG performance raises concerns about the subjectivity of our enterprise-level ESG rating data. Consequently, it is necessary to consider additional third-party ESG information and even develop more suitable ESG performance measures for domestic enterprises to validate our findings. Third, our study focuses on the GI impact of ESG performance at the enterprise level in China, which limits its generalizability to other settings. With the increasing availability of economic data, more efforts could delve into the GI effects of ESG performance at both the industry and macro levels. In addition, it is promising for future research to evaluate the effectiveness of corporate ESG performance on green development in other developing countries.

Uncited references

Andries and Sprincean, 2023; Hsu and Chen, 2023.

CRediT authorship contribution statement

Hua Zhang: Conceptualization, Data curation, Methodology, Software, Validation. **Jie Lai:** Data curation, Formal analysis, Investigation, Methodology, Software, Writing – original draft, Writing – review & editing. **Shuijing Jie:** Writing – review & editing.

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.

Data availability

The authors do not have permission to share data.

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Appendix C. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2024.120272.

Appendix A. Prior literature evaluating the impact of ESG performance on corporate Gl

Prior literature evaluating the impact of ESG performance on corporate Gl.

Article	Main outcome	Sample	Method	Conclusion
GI quantity				
Wang et al. (2023a)	Green patent grants	3,301 listed enterprises, China, 2013–2019	DID, PSM-DID, GMM	Significant positive impact
Yang et al. (2023)	Green patent applications	559 listed enterprises, China, 2013–2019	OLS, IV	Significant positive impact
Zhai et al. (2022)	Green patent applications	1,577 listed enterprises, China, 2016–2020	Zero-inflated Poisson	Significant positive impact
Zheng et al. (2023)	Green invention patent applications, Green utility patent applications	770 listed enterprises, China, 2011–2020	Dynamic OLS, Panel vector error correction model	Significant positive impact
GI quantity and GI quality				
Tan and Zhu (2022)	Green patent applications, Green patent application citations	China, 2010–2018	DID, OLS PSM-DID	Significant positive impact
Our study	Green invention patent applications, Green invention patent application citations	2,879 listed enterprises, China, 2009–2021	TWFE, IV, DID	Significant positive impact

Appendix B. Definitions and data sources of main variables

TableB
Variables, definitions, and data sources.

Variable	Definition	Source
Outcome variables		
Log(1 + IAN)	Log of "1 + the number of green invention patent applications each year"	GPRD of the CNRDS database
Log(1 + IAC)	Log of "1 + the number of citations to green invention patent applications within five years"	
Key independent variable		

ESG	ESG ratings averaged over four quarters per year	Wind database
Control variables		
Size	Log of total assets	CSMAR database
Lev	The total liabilities are divided by the total assets	
Roa	The net profit divided by the average total assets	
Growth	The operating income divided by the previous year's operating income	
Fixed assets ratio	The net fixed assets divided by total assets	
Cash flow	The net cash flow from operating activities divided by total assets	
Log(Age)	Log of the enterprise's age since it was established	
Duality	= 1 if the chairman of the board and the managing director are the same person; = 0 otherwise	
Board	Log of the number of board directors	
Supervisor	Log of the number of directors on the supervisory board	
Independence	The number of independent directors divided by that of board directors	
Holder	Percentage of shares held by top ten shareholders (%)	
Channel variables		
Financial constraints	The absolute value of the SA index	CSMAR database
Agency costs	Management costs divided by operating income	
R&D expenditure	R&D expenditure divided by total assets (%)	
Instrumental variables		
$Log(Contemple_1+1) \times HDI$	The interaction term between the log of "the number of Confucian temples within a 450 km radius of each city + 1" and the previous year's HDI	CFCN of the CNRDS database; Human Development Reports (https://hdr.undp.org/data-center)
$Log(Contemple_2+1) \times HDI$	The interaction term between the log of "the number of Confucian temples within a 500 km radius of each city + 1" and the previous year's HDI	

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