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Empowering ESG: The pivotal influence of directors' and officers' liability insurance on corporate sustainability

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ABSTRACT

Using annual data from Chinese A-share listed companies between 2009 and 2023, this paper investigates the impact of Directors' and Officers' (D&O) liability insurance on corporate Environmental, Social, and Governance (ESG) performance, as well as the underlying mechanisms. The results show that D&O liability insurance significantly improves corporate ESG performance, and this finding remains robust after a series of robustness checks. Furthermore, we unveil the 'black box' through which D&O liability insurance enhances ESG performance. Further research findings indicate that the impact of D&O liability insurance on corporate ESG performance exhibits significant heterogeneity. Specifically, the level of regional green finance development, institutional investor shareholding, and tax incentive levels enhance the positive influence of D&O liability insurance on corporate ESG performance. In contrast, for heavily polluting industries, the improvement effect of D&O liability insurance on ESG performance is notably weaker compared to non-heavily polluting industries. Lastly, we explored the impact of the COVID-19 pandemic on this relationship and found that during the pandemic, the positive effect of D&O liability insurance on corporate ESG performance was significantly weakened. This suggests that in the context of a global crisis, companies prioritize short-term survival goals over long-term sustainable development objectives. This study not only contributes to the literature on risk transfer mechanisms but also deepens the understanding of how D&O liability insurance enhances corporate ESG performance.

1. Introduction

A large body of literature has concluded that Directors and Officers (D&O) liability insurance significantly enhances corporate value (Hwang & Kim, 2016; O'Sullivan, 1997). This is because D&O liability insurance reduces the legal risks faced by management, mitigates agency problems, and alleviates risk aversion among executives, allowing them to confidently pursue long-term growth opportunities for the company. However, a significant amount of research also indicates that the impact of D&O liability insurance on corporate value is not unidirectional but rather contingent on the state of internal governance (Fung & Yeh, 2018). While D&O liability insurance may strengthen a company's internal control capabilities through external oversight, thereby improving corporate value, it

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may also lead to an increase in agency costs due to the presence of moral hazard, which in turn weakens corporate value (Aguir & Aguir, 2019; Fung & Yeh, 2018).

Although existing studies have explored the relationship between ESG performance and various managerial characteristics (Deng et al., 2024; Devos et al., 2024; Fan et al., 2024), few have examined the link between D&O liability insurance and corporate ESG performance (Tang et al., 2023). Current literature predominantly focuses on how D&O liability insurance enhances corporate governance by reducing management's legal risks (O'Sullivan, 1997; Core, 1997) or strengthens internal controls through external oversight (Fung & Yeh, 2018). However, there is no theoretical consensus on whether D&O liability insurance simultaneously plays a dual role in both moral hazard and regulatory oversight mechanisms.

On one hand, according to moral hazard theory, D&O liability insurance may weaken management's sense of accountability for the consequences of their decisions, leading to short-term behavior and neglect of long-term sustainable development (Aguir & Aguir, 2019). For example, management may be more inclined to pursue high-risk projects with higher short-term returns to meet shareholders' demands for immediate financial performance. Such short-termism increases agency costs, reduces investments in ESG initiatives, and ultimately weakens corporate ESG performance. On the other hand, regulatory oversight theory suggests that the existence of D&O liability insurance compels insurers to systematically monitor managerial behavior, particularly in ESG-related areas, to mitigate potential legal risks (O'Sullivan, 1997). For instance, if a company neglects environmental management, it may face environmental accidents that lead to litigation risks and substantial compensation liabilities. To avoid these consequences, management tends to adopt more cautious strategies in key areas such as environmental protection, social responsibility, and corporate governance (Chen & Li, 2010; Lin & Lin, 2013). Thus, D&O liability insurance may encourage companies to strengthen their ESG management through external oversight mechanisms, thereby improving their ESG performance.

Currently, the interplay between these two mechanisms and their combined impact on corporate ESG performance remain underexplored. This study aims to reveal the pathways through which D&O liability insurance operates under both mechanisms and analyze its specific effects on corporate ESG performance.

Does purchasing D&O liability insurance prompt listed companies to lower their ESG performance? Or, under otherwise equal conditions, does it incentivize companies to improve their ESG practices? Currently, while a few studies (e.g., Tang et al., 2023) have begun to examine the impact of D&O liability insurance on corporate ESG performance, most research remains focused on its effects on corporate value and financial performance, lacking in-depth analysis of the mechanisms through which D&O liability insurance operates. Furthermore, existing literature has not sufficiently explored the heterogeneous effects of D&O liability insurance on ESG performance, particularly across different market environments and corporate characteristics. For instance, some studies suggest that the presence of D&O liability insurance may encourage more cautious decision-making among management in high-risk industries (Core, 1997), but this effect may vary across industries, regions, or corporate governance structures. This indicates that the mechanism of D&O liability insurance may be jointly moderated by external environments and internal characteristics.

As an emerging market, China possesses a corporate governance structure, regulatory environment, and marketization level distinct from those of mature markets such as the United States and Europe. Its enterprises play a pivotal role in global supply chains and markets, and they are increasingly becoming a focal point for global investors and regulators in the ESG domain (Li, 2024). On the one hand, the unique characteristics of the Chinese market, along with the relatively low penetration rate of D&O liability insurance, provide an ideal experimental setting for studying the impact of D&O liability insurance on corporate behavior. For instance, the coverage rates of D&O liability insurance in Taiwan, the United States, and Canada are 57 %, 97 %, and 86 %, respectively (Lai & Tai, 2019). In contrast, this proportion for Chinese listed companies was only 7.3 % in 2018 and 15 % in 2020 (Li et al., 2022). On the other hand, as China's capital market rapidly develops, companies are becoming increasingly reliant on external oversight. Research into the influence of D&O liability insurance on corporate behavior in this context offers new perspectives for global corporate governance studies.

In light of this, this study utilizes data from Chinese A-share listed companies from 2009 to 2023 to examine the impact of D&O liability insurance on corporate ESG performance and its underlying mechanisms. The results indicate that D&O liability insurance significantly enhances corporate ESG performance, demonstrating its role as an effective external oversight mechanism that guides management to focus more on sustainable development. This conclusion is supported by a series of robustness tests, including indicator replacement, year-by-year propensity score matching, robust standard errors at different levels, placebo tests, and instrumental variable regression. Further analysis reveals that D&O liability insurance primarily improves ESG performance by promoting green innovation, encouraging the adoption of financial technology, and strengthening internal controls. Additionally, the positive impact of D&O liability insurance on ESG performance exhibits significant heterogeneity: the effect is more pronounced in regions with higher levels of green finance development, companies with higher institutional investor ownership, and firms benefiting from greater tax incentives. However, in heavily polluting industries, the positive effect of D&O liability insurance is relatively weaker, likely due to higher environmental compliance costs and complex governance challenges, which may divert resources toward short-term compliance needs rather than long-term ESG improvements.

The marginal contribution of this paper lies in the following: Firstly, although existing literature widely discusses the impact of Directors' and Officers' (D&O) liability insurance on managerial behavior and corporate governance (Coelho et al., 2024; Devos et al., 2024), we have chosen a less explored angle, namely, how D&O liability insurance as a management tool influences corporate ESG performance under different moral hazard and regulatory effects. This novelty not only expands the existing research domain but also provides new theoretical perspectives, deepening our understanding of D&O liability insurance under different mechanisms. Secondly, this paper breaks through the traditional analytical framework of corporate ESG behavior by moving beyond a sole focus on internal management practices (Boulhaga et al., 2023; Gebhardt et al., 2023) or external environmental factors (Li, Tang, et al., 2024; Mooneeapen et al., 2022). For the first time, it systematically considers the role of D&O liability insurance as an external supervisory

mechanism, offering a new, multidimensional perspective to understand corporate ESG behavior and its determinants. Lastly, based on empirical analysis of Chinese sample enterprises, we reveal how D&O liability insurance uniquely impacts corporate ESG behavior within the specific legal, economic, and cultural context of China, addressing the lack of attention in international research towards developing countries (Boyer, 2007) and providing significant reference for emerging market nations.

2. Theoretical framework

In this section, we theoretically explain the impact of Directors and Officers (D&O) liability insurance on corporate ESG performance and its potential mechanisms, specifically how D&O liability insurance influences corporate green innovation, fintech development, and the quality of internal controls, ultimately affecting ESG performance.

2.1. D&O liability insurance, corporate green innovation, and ESG performance

As an effective risk transfer mechanism, D&O liability insurance reduces the personal liability risks executives face when making innovation decisions, thereby encouraging management to make bolder strategic investments. Green innovation (e.g., clean technologies, sustainable product development) often involves high costs, high risks, and long timeframes, which may lead executives to avoid these projects out of fear of failure or legal responsibility (Rennings, 2000). However, D&O liability insurance provides liability protection, alleviating concerns about legal consequences and making executives more proactive in pursuing green innovation (Han et al., 2024). This incentive mechanism encourages executives to engage in high-risk, high-reward green innovation projects.

According to the theory of information asymmetry, corporate decisions and actions are often difficult for external stakeholders (such as investors, regulators, and the public) to fully understand (Chen and Liu, 2013). During the underwriting process for D&O liability insurance, insurers conduct detailed risk assessments of a company's environmental risks, social responsibilities, and governance structures. This scrutiny serves as an external oversight mechanism, enhancing transparency in corporate governance and environmental risk management (Chang et al., 2018). If a company has significant environmental management issues, it may face higher premiums or restrictions on insurance coverage. Therefore, to lower insurance costs, companies are incentivized to improve their environmental practices and reduce the risk of environmental violations (Liu, 2024). This risk-control behavior drives companies to prioritize green innovation by adopting sustainable technologies and environmental projects to mitigate potential future litigation and regulatory penalties.

The market signaling theory suggests that in situations of information asymmetry, companies often convey signals about their quality or strategy through specific actions or decisions, which, in turn, influence the judgments of external investors and stakeholders (Spence, 1978; Zerbini, 2017). Griffith (2006) advocates for the mandatory disclosure of D&O liability insurance policy details, as the rigorous underwriting process signals a company's governance and risk management strengths, particularly in addressing environmental and social responsibilities. Although research indicates that companies with D&O liability insurance may be more likely to face lawsuits (Gillan & Panasian, 2015), those that purchase such insurance typically demonstrate strong risk control and transparency in management, boosting external investors' confidence in the company's long-term sustainability and governance structure. Particularly in situations of information asymmetry, D&O liability insurance serves as an effective market signal, helping companies build credibility and enhance investor trust (Liao et al., 2022). This trust not only elevates the company's market reputation but also significantly reduces financing costs and constraints (Lin et al., 2013). External investors and financial institutions often adjust financing conditions based on a company's risk profile. Firms that purchase D&O liability insurance gain more financing opportunities and more favorable terms due to their transparency in legal compliance and governance risks (Zhang et al., 2023; Zhao et al., 2024). This creates favorable conditions for companies to secure long-term funding, particularly for green innovation projects, enabling them to effectively undertake high-risk, long-term sustainable development initiatives. By alleviating financing constraints and securing long-term capital support, companies can significantly enhance their competitiveness in green innovation. Adequate funding allows firms to invest more boldly in green technology research and sustainable production, without abandoning these long-term, high-reward innovation projects due to financial constraints or pressure (Yu et al., 2021; Zhang & Jin, 2021).

Green innovation introduces clean technologies, energy-saving and environmentally friendly processes, and the development of sustainable products, which not only reduces a company's environmental footprint but also enhances its ability to adapt to external environmental policies and regulations (Xie et al., 2023). By actively engaging in green innovation, companies demonstrate a strong commitment to environmental responsibility, leading to higher scores in the environmental dimension (E) of ESG evaluations. Additionally, green innovation improves the company's social interactions, boosting its performance in the social responsibility (S) dimension (Nguyen Dang et al., 2022). As consumers and stakeholders increasingly demand green products and sustainable development, green innovation enables companies to better meet these demands (Novitasari & Tarigan, 2022). By providing sustainable products and services to the market, companies not only meet societal expectations for environmentally friendly practices but also enhance their social reputation and sense of responsibility (Gomez-Trujillo et al., 2020; Quintana-García et al., 2022), further strengthening their ESG performance.

Furthermore, green innovation is often closely tied to corporate governance (Amore & Bennedsen, 2016). Implementing green innovation requires companies to have sound governance structures and long-term strategic planning to ensure that innovation initiatives are effectively carried out. By enhancing corporate governance, companies not only optimize risk management but also improve decision-making transparency and operational efficiency, thereby boosting their performance in the governance (G) dimension. Finally, there is extensive literature exploring the impact of green innovation on corporate ESG performance. For example, Long et al. (2023) found that ESG performance significantly enhances green innovation, particularly in countries with weaker green

innovation capacities, where the positive effect of ESG performance on green innovation is more pronounced. Tan and Zhu (2022) also discovered that ESG ratings significantly promote green innovation among Chinese listed companies, primarily by alleviating financial constraints and strengthening managers' environmental awareness. Similarly, Xu et al. (2022) examined the impact of green innovation on corporate ESG performance using a sample of Chinese listed companies and found that green innovation significantly improves a company's ESG outcomes.

2.2. D&O liability insurance, corporate fintech level, and ESG performance

Extensive literature on risk management theory (Nocco & Stulz, 2006; Stulz, 2008; Bromiley et al., 2015) has demonstrated that risk management plays a crucial role in corporate strategic development. As an effective risk transfer mechanism, D&O liability insurance reduces the legal risks executives face from erroneous decisions, thus alleviating their concerns during decision-making. This risk transfer mechanism enables executives to confidently drive corporate innovation and the application of financial technology (fintech). Fintech innovation involves high risks, particularly in areas like data security, privacy protection, and regulatory compliance (Leong & Sung, 2018), which are key components of corporate governance (Ashraf, 2022). With the protection of D&O liability insurance, corporate executives can take on greater innovation risks in fintech projects, thereby promoting the application of cutting-edge technologies such as digital technology, blockchain, and artificial intelligence (Liu et al., 2021). The effective use of these technologies enhances corporate governance performance, improves decision-making transparency, and strengthens risk management capabilities (Wen et al., 2023), leading to better ESG performance.

Moreover, according to information asymmetry theory, insurers conduct rigorous evaluations of a company's governance structure, financial transparency, and risk management systems before offering D&O liability insurance (MacMinn et al., 2012). To pass these evaluations and obtain better insurance terms, companies typically need to improve their fintech applications. By utilizing big data, blockchain, and AI technologies, companies can enhance the precision and timeliness of financial reporting (Roszkowska, 2021) and improve internal governance transparency (Najaf et al., 2024). Research has shown that blockchain technology ensures the immutability of financial data, contract execution, and supply chain management, significantly increasing transparency and data security (Pan et al., 2020). Simultaneously, AI and big data analytics substantially improve the accuracy of early warning systems, helping companies effectively identify potential risks (Shah et al., 2023). Therefore, fintech plays a crucial role in enhancing data transparency and compliance, reinforcing the external oversight function of D&O liability insurance, and optimizing corporate financial management and risk control (Chen et al., 2019; Hendershott et al., 2021). These advancements in governance structure contribute to improved ESG performance (Dicuonzo et al., 2024; Ding et al., 2024; Wang et al., 2022).

Finally, based on signaling theory, the periodic audits and risk assessments conducted by insurers create external pressure on companies to continuously improve their fintech applications (Bag et al., 2021), thereby enhancing the transparency and timeliness of financial disclosures (Rerung et al., 2024). Through transparent governance and financial practices, companies signal their quality to the market, reducing information asymmetry, boosting investor confidence, and ultimately lowering financing costs (Ding et al., 2022). This provides companies with the financial support needed to invest in environmental protection, social responsibility initiatives, and governance structure improvements, further enhancing their ESG performance (Mu et al., 2023).

2.3. D&O liability insurance, corporate internal control, and ESG performance

Existing literature, grounded in risk management theory, indicates that executives often face potential legal risks related to financial misconduct, insufficient information disclosure, and failures in social responsibility when implementing major management measures and internal controls (Beasley et al., 2005). D&O liability insurance provides legal risk protection for executives, enabling them to be more proactive in optimizing internal control systems without being deterred by the fear of legal consequences (Chen & Keung, 2018). With the protection of this risk mitigation mechanism, management can focus on improving the quality of internal controls (Lai & Tai, 2019), effectively preventing financial misconduct, environmental issues, and social responsibility deficiencies. This improved risk management reduces operational uncertainties and directly enhances corporate ESG performance (Harasheh & Provasi, 2023).

Incentive compatibility theory reveals how D&O liability insurance adjusts the incentive structure for executives, aligning their actions more closely with the long-term interests of the company. This theory explains how D&O liability insurance, by sharing risk, reduces the legal and financial risks faced by executives in decision-making, thus encouraging them to take more proactive steps in building internal control systems. To avoid personal legal risks, executives might sometimes adopt a conservative or passive approach, avoiding institutional innovation that could pose compliance risks (Chalmers et al., 2002). D&O liability insurance reduces the personal liability risk of executives, making them more proactive in improving internal controls and promoting compliance management (Li, Tang, et al., 2024). This incentive compatibility mechanism ensures that executives' actions align with the long-term interests of the company, driving the optimization of internal controls and the enhancement of corporate value, ultimately improving overall ESG performance (Koo & Ki, 2020; Moffitt et al., 2024).

Finally, based on agency theory, executives, as agents, may tend to pursue short-term benefits while neglecting the company's long-term development and social responsibility (Gu, 2023). D&O liability insurance introduces external supervision, pushing companies to be stricter in governance structures, financial transparency, and compliance. The underwriting scrutiny by insurance companies forces management to strengthen internal controls, reduce agency problems, and ensure the effective implementation of policies (Chen & Keung, 2018). An effective internal control system not only improves financial transparency and compliance but also lowers the legal and financial risks associated with environmental and social responsibility failures, thereby enhancing corporate ESG performance

(Yeh et al., 2024). Based on the above analysis, the theoretical framework of this paper is illustrated in Fig. 1.

3. Data, variables, and methods

3.1. Sample selection

This study selects A-share listed companies on the Shanghai Stock Exchange and Shenzhen Stock Exchange as the initial sample. Given that the ESG performance scores by Shanghai Huazheng Index were first disclosed in 2009, we set the sample period from 2009 to 2023. To enhance the stability of the sample and the reliability of the analysis results, we processed the data as follows: First, we excluded the financial and insurance industries due to their significantly different financial characteristics, which could affect the comparability of metrics. Second, we removed PT, ST, and ST* companies, as these firms typically face financial distress or delisting risks, and their abnormal financial conditions could exert extreme influences on the results. Additionally, we excluded firms with a return on assets (ROA) greater than 1 or less than −1 to eliminate outliers or abnormal data, ensuring the analysis reflects normal operating conditions. Finally, we removed companies with a board size of 0, an independent director ratio of 0, or a debt-to-asset ratio greater than 1, as these firms exhibit abnormal governance structures or financial conditions that may not represent typical corporate operations. Our final valid sample consists of 40,446 panel data points from 4213 companies, with the annual frequency distribution of firms detailed in Table A1 of the Appendix.

3.2. Variable selection and model construction

To measure corporate ESG performance, we utilize the ESG scores provided by Shanghai Huazheng Index Information Service Co., Ltd. Their ESG rating system is structured around three main pillars: environment, social, and corporate governance. It further breaks down into 16 thematic areas, including climate change, resource utilization, human capital, product responsibility, shareholder rights, and governance structure, which are assessed across 44 key indicators. ESG scores range from 0 to 100, where a higher score indicates better ESG performance. The corresponding ESG rating categories include C, CC, CCC, B, BB, BBB, A, AA, and AAA, with nine levels in total. In this study, we use the ESG score as the main dependent variable, as it provides a more accurate reflection of changes in corporate ESG performance than the ESG rating levels.

Our primary independent variable is a dummy variable indicating whether the company has purchased Directors and Officers (D&O) liability insurance. It takes the value of 1 if the company purchased D&O liability insurance in a given year, and 0 otherwise. Based on existing literature (Egger et al., 2015; Kim & Hwang, 2016; Zhang et al., 2023; Shen et al., 2023), we include a range of control variables that may affect corporate ESG performance, including total assets (size), firm age (age), cash holdings (cash), return on assets (roa), leverage ratio (leverage), total number of board members (board), whether the chairman and CEO positions are held by the same person (dual), the shareholding ratio of the largest shareholder (top1), the proportion of independent directors (indep), and whether the firm is a state-owned enterprise (soe). This ensures the comprehensiveness and accuracy of the analysis. ESG performance data comes from the Huazheng database and Bloomberg database, while other variables are sourced from the Wind database, CSMAR database, and CNRDS database. Detailed definitions and data sources for each variable are provided in Table A2 of Appendix.

$$esgscore_{t+1} = \beta_0 + \beta_1 Insured_{i,t} + \beta_2 Controls_{i,t} + \sum Firm_{i,t} + \sum Year_{i,t} + \varepsilon_{i,t} \quad (1)$$

To address potential endogeneity caused by reverse causality, the comprehensive ESG score in this study refers to the ESG score of the following period, i.e., the ESG score in period t+1 ($esgscore_{t+1}$). Controls include a range of firm characteristics and corporate governance variables. Firm and Year represent firm and year fixed effects, respectively. The firm fixed effects control for time-invariant firm-specific characteristics that may affect the firm's ESG performance, while the year fixed effects capture the common shocks across different years due to macroeconomic conditions, policy changes, or other time-related factors impacting firms' ESG performance. The term $\varepsilon_{i,t}$ denotes the random error term, which accounts for omitted variables, measurement errors, or pure randomness in the model.

In this study, Insured represents whether a firm has purchased D&O liability insurance, and it is an indicator variable. We are

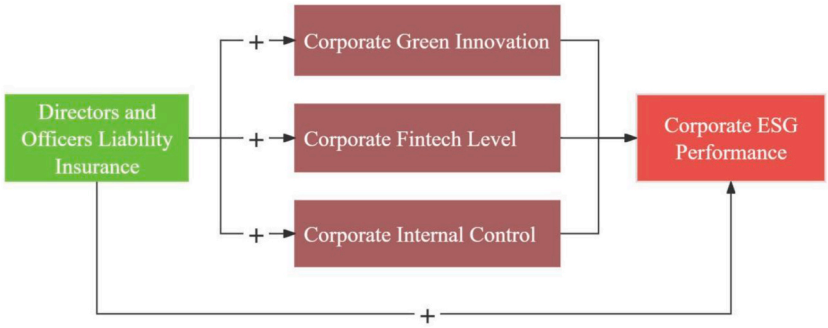

Fig. 1. Theoretical framework.

primarily interested in the coefficient estimate of this variable. A linear regression model is used to estimate the econometric model (1). In the baseline regression model, to address potential serial correlation within the same firm across different years, we cluster the standard errors at the firm level.

3.3. Descriptive statistics

Table 1 presents the descriptive statistics of our key variables. Following the approach of Zhao and Wang (2024), we assign values to the Huazheng ESG ratings, where the rating levels range from C, CC, CCC, B, BB, BBB, A, AA, to AAA, corresponding to values from 1 to 9, with higher values indicating better ESG performance. The average ESG rating published by Huazheng is 4.1256, which corresponds to a rating between B (assigned a value of 4) and BB (assigned a value of 5). This means that the ESG performance of most sample firms is at a relatively moderate level, falling within the low-risk or compliant range. The independent variable, Insured, indicates whether the company purchased or renewed its D&O liability insurance in the given year. The mean value shows that 8.91 % of the sample firms purchased D&O liability insurance. This proportion reflects the relatively low penetration of D&O liability insurance in the Chinese A-share market, which may be related to the limited attention most companies pay to potential legal liabilities or the inadequate enforcement of relevant regulations.

4. Empirical results analysis

4.1. Baseline results

Table 2 reports the estimation results of the econometric model (1). In Column (1), aside from including the variable Insured, only firm fixed effects are controlled for. The coefficient estimate for Insured is 1.0981 and is statistically significant at the 1 % level. Since macroeconomic conditions and policy changes in different years can significantly impact firms' ESG performance, we include year fixed effects in Column (2). We find that the coefficient estimates for Insured increases slightly to 0.8949, remaining significant at the 1 % level. In Column (3), we further control for firm-specific characteristics, such as firm size (lnsize), firm age (lnage), cash holdings (cash), return on assets (roa), and leverage (leverage). The coefficient for Insured is estimated at 0.7754, and it remains significant at the 1 % level. Finally, in Column (4), we add controls for corporate governance characteristics, including board size (lnboard), CEO power (dual), ownership concentration (top1), the proportion of independent directors (indep), and whether the firm is state-owned (soe). We find that the coefficient for Insured is 0.7816, which remains significant at the 1 % level. Overall, across Columns (1) to (4), the coefficient estimate for Insured remains positive and statistically significant at the 1 % level. Moreover, the changes in the coefficient estimates and standard errors across the columns are minimal. This indicates that the positive impact of purchasing Directors, Supervisors, and Senior Executives Liability Insurance on corporate ESG performance is stable and robust.

We consider the results from Column (4) as our preferred baseline. Based on these results, purchasing D&O liability insurance leads to an average increase of 0.7816 in a firm's ESG score. Given that the current average ESG score is 73.15, this implies a relative improvement of approximately 1.07 % (0.7816/73.15). While the improvement in ESG performance may seem modest, it represents a meaningful enhancement in long-term sustainability, particularly in highly competitive markets where incremental improvements can significantly differentiate firms.

Table 1
Descriptive statistics.

Variable	Obs	Mean	Std.	Min	Max
$esgscore_{t+1}$	40,446	73.15	4.979	36.62	91.55
$esggrade_{t+1}$	40,785	4.1256	0.9351	1	8
Insured	40,446	0.0891	0.285	0	1
gfindex	40,437	0.398	0.116	0.0576	0.657
Pollute	40,446	0.228	0.419	0	1
Inshare	39,962	15.42	21.77	0	98.58
taxpre	40,446	0.156	0.209	0	0.841
greeninno	41,703	5.4586	15.052	0	98
lnfintech	41,720	3.2497	1.4571	0	7.546
lncscore	40,893	6.2723	1.1400	0	6.904
lnsize	40,446	12.90	1.333	5.731	19.40
lnage	40,446	2.885	0.367	0.693	4.290
cash	40,446	17.25	14.00	0.0363	99.25
roa	40,446	3.905	7.226	−96.52	78.59
leverage	40,446	41.82	20.70	0.708	99.76
soe	40,446	0.352	0.478	0	1
lnboard	40,446	2.127	0.200	1.386	2.890
dual	40,446	0.292	0.455	0	1
top1	40,446	34.58	15.05	0.286	89.99
indep	40,446	37.43	5.457	14.29	80

Table 2
Baseline results.

VARIABLES	(1)	(2)	(3)	(4)
	$esgscore_{t+1}$	$esgscore_{t+1}$	$esgscore_{t+1}$	$esgscore_{t+1}$
Insured	1.0981***	0.8949***	0.7754***	0.7816***
	(0.1621)	(0.1699)	(0.1640)	(0.1631)
lnsize			0.8093***	0.8132***
			(0.0732)	(0.0732)
lnage			0.3371	0.4430
			(0.4421)	(0.4493)
cash			0.0146***	0.0145***
			(0.0027)	(0.0027)
roa			0.1001***	0.0993***
			(0.0051)	(0.0051)
leverage			−0.0292***	−0.0293***
			(0.0030)	(0.0030)
soe			0.5153**	0.5793***
			(0.2146)	(0.2153)
lnboard				−0.0105
				(0.3020)
dual				0.0374
				(0.0942)
top1				0.0090*
				(0.0052)
indep				0.0359***
				(0.0087)
Firm FE	Yes	Yes	Yes	Yes
Year FE	No	Yes	Yes	Yes
Constant	73.0543***	73.0724***	62.0729***	60.0577***
	(0.0144)	(0.0151)	(1.5189)	(1.7651)
Observations	40,446	40,446	40,446	40,446
R-squared	0.5008	0.5072	0.5328	0.5335

Note: Clustered robust standard errors at the firm level (in parentheses), ***p < 0.01, **p < 0.05, *p < 0.1.

4.2. Robustness tests

4.2.1. Alternative measurement

ESG composite scores reflect the overall performance in three key areas: Environment (E), Social (S), and Governance (G). However, different firms may have significant variations in their strategies and performance across these dimensions. Conducting separate regression analyses for each ESG sub-dimension (E, S, and G) allows for a deeper understanding of how D&O liability insurance affects each specific area of ESG and reveals differences in its impact. Columns (1) to (3) in Table 3 report the results of the regressions for Environmental (E), Social (S), and Governance (G) performance. We find that D&O liability insurance has a significant positive impact on these dimensions at the 10 % level, with coefficients of 1.3688, 0.6502 0.3667, respectively, and significance levels of 1 %, 5 %, and 10 %. These results suggest that D&O liability insurance has varying degrees of influence across the ESG dimensions, with the impact being strongest in the environmental and social areas. Overall, the insurance drives significant improvements in all three ESG dimensions, with a particularly strong effect on environmental protection and social responsibility. This implies that D&O liability insurance is not merely a tool to protect executives' interests, but also serves as a key driver of corporate improvement in ESG performance. After purchasing D&O liability insurance, executives become more attuned to environmental and social responsibilities, fostering greater sustainability. Although the impact on governance is smaller, the insurance still contributes to optimizing corporate

Table 3
Regression results of alternative measurement.

VARIABLES	(1)	(2)	(3)	(4)	(5)
	$escore_{t+1}$	$sscore_{t+1}$	$gscore_{t+1}$	$esggrade_{t+1}$	ESG_pengbo_{t+1}
Insured	1.3688***	0.6502**	0.3667*	0.1370***	2.9787***
	(0.2770)	(0.2933)	(0.2082)	(0.031)	(0.4860)
Firm-level controls	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Constant	41.7824***	53.3464***	75.0188***	1.3947***	6.3787
	(2.4961)	(3.2679)	(2.2745)	(0.3465)	(4.8751)
Observations	40,446	40,446	40,446	40,785	12,947
R-squared	0.5651	0.5313	0.5080	0.5213	0.8244

Note: Clustered robust standard errors at the firm level (in parentheses), ***p < 0.01, **p < 0.05, *p < 0.1.

governance structures, thereby enhancing long-term stability and competitiveness.

ESG composite scores and ESG composite ratings represent two different ways of evaluating a company's ESG performance. To verify the robustness of the model, we first used ESG composite scores as the dependent variable in our regression analysis. Next, we substitute the composite score with the ESG composite rating to test the model's sensitivity to different evaluation methods. If the coefficient for Insured obtained using ESG composite ratings is consistent with the results obtained using ESG composite scores, this suggests that the model's estimation is not sensitive to the evaluation method, making the conclusions more reliable and robust. Conversely, if there is a significant difference, it would indicate sensitivity to different evaluation methods. Column (4) in Table 3 reports the results of the regression using the ESG composite rating as the dependent variable. The results show that Insured has a significantly positive coefficient at the 1 % level, indicating consistency between the results obtained with ESG composite ratings and those using ESG composite scores. This confirms that the baseline regression results are robust and not sensitive to different ESG evaluation methods.

Different rating agencies may use varying metrics, weights, and methodologies when evaluating a company's ESG performance. Therefore, in this study, we not only use Shanghai Huazheng Index Information Service Co., Ltd. (Huazheng) ESG score as the dependent variable but also include the Bloomberg ESG score to further verify the robustness and generalizability of the results across different data sources and evaluation systems. This approach helps mitigate potential bias from relying on a single data source, ensuring the reliability and broader applicability of the study's findings. The results of the regression using the Bloomberg ESG composite score as the dependent variable are reported in Column (5) of Table 3. The results show that the coefficient for Insured is significantly positive at the 1 % level, indicating that D&O liability insurance has a significant positive effect on corporate ESG performance. Given that the coefficient for Insured is 2.9787 and the average Bloomberg ESG score is 29.9046, purchasing D&O liability insurance would result in an 9.96 % (2.9787/29.9046) increase in the average ESG composite score.

4.2.2. Year-by-year propensity score matching (PSM)

The decision to purchase D&O liability insurance is not a random event; although companies voluntarily purchase this insurance, many factors influence whether a firm opts for this coverage. These factors may include company size, age, financial condition, management's risk preferences, among others, which could also affect a company's ESG performance. Therefore, if these factors are not properly controlled for, the direct estimation of the impact of D&O liability insurance on corporate ESG performance could be biased due to self-selection. By applying year-by-year Propensity Score Matching (PSM), we match companies with similar probabilities of purchasing D&O liability insurance, effectively making the purchase decision approximate random allocation within the matched sample. This method controls for self-selection bias and allows us to more accurately evaluate the impact of D&O liability insurance on ESG performance while minimizing the interference of other confounding factors, thereby enhancing the credibility of

Table 4
Regression results using year-by-year PSM.

VARIABLES	(1)	(2)	(3)	(4)
	$esgscore_{t+1}$	$esgscore_{t+1}$	$esggrade_{t+1}$	$esggrade_{t+1}$
Insured	0.8694***	0.7593***	0.1592***	0.1303***
	(0.1739)	(0.1670)	(0.0322)	(0.0307)
lnsize		0.8397***		0.1979***
		(0.0767)		(0.0133)
lnage		1.5472***		0.1386
		(0.4863)		(0.0922)
cash		0.0158***		0.0041***
		(0.0029)		(0.0005)
roa		0.0981***		0.0135***
		(0.0053)		(0.0009)
leverage		−0.0291***		−0.0071***
		(0.0031)		(0.0006)
soe		0.6031***		0.0879**
		(0.2192)		(0.0388)
lnboard		0.0813		0.0932
		(0.3097)		(0.0587)
dual		0.0252		−0.0088
		(0.0971)		(0.0178)
top1		0.0091*		0.0028***
		(0.0052)		(0.0010)
indep		0.0394***		0.0109***
		(0.0089)		(0.0016)
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Constant	73.0557***	56.1061***	4.0854***	0.5798
	(0.0160)	(1.9210)	(0.0030)	(0.3594)
Observations	38,491	38,491	40,770	40,770
R-squared	0.5125	0.5381	0.5579	0.5860

Note: Clustered robust standard errors at the firm level (in parentheses), ***p < 0.01, **p < 0.05, *p < 0.1.

causal inference.

However, we recognize that each year may be influenced by different external environments, policy changes, economic conditions, etc., which could affect firms' environmental performance. Using pooled PSM may lead to combining samples from different periods that are influenced by varying external factors. For instance, a policy might be in effect in one year but not in others. Mixing these years in regression analysis could lead to incorrect conclusions. Thus, year-by-year PSM ensures higher comparability within the same time period and avoids mismatches caused by varying policy, economic conditions, or external factors across different periods. In this study, we follow the established practice of year-by-year PSM (Bockerman & Ilmakunnas, 2009; Heyman et al., 2007), considering firm characteristics, corporate governance structures, industry traits, and using the radius matching method with a radius of 0.01 for 1:1 matching each year.

From the common support domain after matching, we observe significant overlap between the treated and untreated groups, indicating reliable matching within the common support region, leading to more credible causal inferences (See Figure A1 of Appendix for details). Regarding the reduction of bias, most variables show that bias is almost eliminated post-matching, indicating that the matching process successfully balanced differences between the treated and control groups, making their distribution across covariates more similar, and thus significantly improving the comparability between the groups (See Figure A2 of Appendix for details). Therefore, year-by-year PSM has a remarkable effect, not only enhancing the comparability of the samples but also laying a solid foundation for subsequent causal effect analysis, ensuring the robustness and reliability of the research findings.

After removing samples that fall outside the common support domain through year-by-year PSM (the sample size for $esgscore_{t+1}$ was reduced from the original 40,446 to the current 38,491; the sample size for $esggrade_{t+1}$ was reduced from the original 40,785 to the current 40,770), we conducted a panel double fixed-effects regression using the remaining samples within the common support region. The regression results are reported in Table 4. Columns (1) and (2) of Table 4 show that after controlling for double fixed effects (firm fixed effects and year fixed effects) and adding firm-level control variables, the coefficient for Insured slightly decreases from 0.8694 to 0.7593, with both estimates remaining significant at the 1 % level. Compared to the baseline regression results, the estimates after year-by-year PSM are somewhat larger, but the difference is not substantial. Notably, Columns (3) and (4) report the results of replacing the ESG composite score with the ESG composite rating in the year-by-year PSM analysis. After controlling for double fixed effects and including firm-level control variables, the coefficient for Insured decreases slightly from 0.1592 to 0.1303, and both estimates are significant at the 1 % level. This indicates that D&O liability insurance has a robust and significant positive impact on corporate ESG performance.

4.2.3. Placebo test

To verify whether the causal relationship between D&O liability insurance and corporate ESG performance is genuine or merely due to noise in the data or potential confounding factors, a permutation test is introduced as a placebo method. This approach involves randomly shuffling the treatment variable (i.e., whether the company purchased D&O liability insurance), thereby conducting the hypothesis test in a scenario where no actual causal relationship exists. If significant results still appear under this randomized treatment, it suggests that the original significance may not stem from the true impact of D&O liability insurance but rather from random correlations or other hidden factors. Conversely, if no significance is found after randomization, it reinforces our confidence that the relationship observed in the original analysis reflects a true causal effect. Therefore, the permutation test helps eliminate these

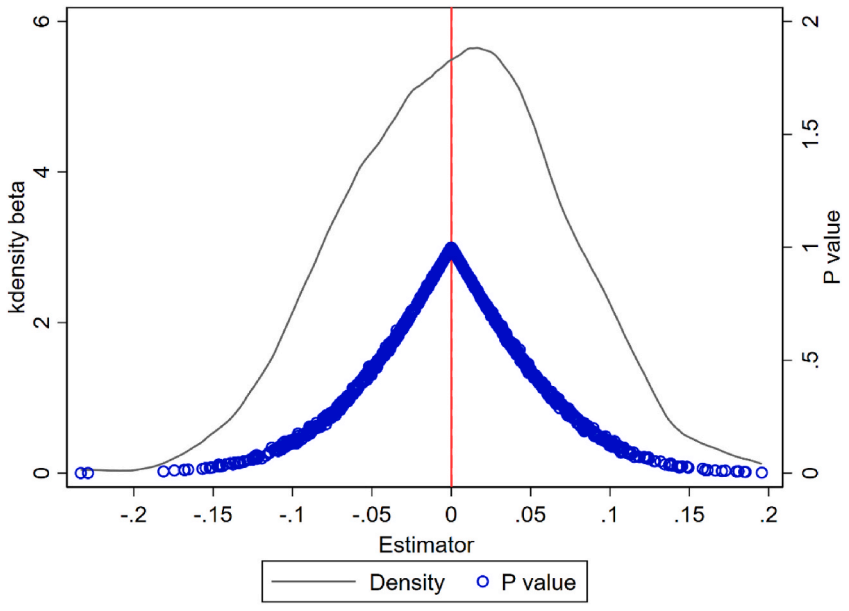

Fig. 2. Results of the permutation test.

spurious relationships and ensures that the study's conclusions genuinely reflect the impact of D&O liability insurance on corporate ESG performance, rather than being the result of certain inherent characteristics of the companies or external environmental factors.

The results of the permutation test are shown in Fig. 2, which illustrates the density distribution of 1000 estimates after randomly shuffling the treatment variable. This distribution takes a bell-shaped form, with most estimates concentrated near zero. Meanwhile, the original estimate from the real data was 0.7816, which is significant at the 1 % level. This indicates that the original estimate is significantly higher than the distribution of estimates from the randomized treatment, suggesting that the original result is not merely an accidental random occurrence but is likely to reflect the true impact of D&O liability insurance on corporate ESG performance. In other words, the permutation test strengthens our confidence in the causal relationship identified in the original analysis, suggesting that D&O liability insurance does indeed have a significant positive impact on corporate ESG performance. This suggests that the role of D&O liability insurance is not confined to a specific evaluation framework, and its effects persist across different assessment standards, reflecting the driving force of D&O liability insurance in promoting corporate social responsibility and sustainability commitments.

4.2.4. Robust standard errors clustered at different levels

Although the earlier regression results indicate that the purchase of D&O liability insurance has a significant positive impact on corporate ESG performance, it is important to account for the potential correlation among firms within the same region. This is because companies within the same county may be influenced by similar geographic, economic, social, and policy environments, which can lead to significant correlations in their ESG performance. If this correlation is not properly addressed in the regression analysis, it may result in autocorrelation in the error terms, leading to underestimated standard errors, overstated significance, and biased estimates (Cameron & Miller, 2015). Therefore, to accurately assess the impact of D&O liability insurance on ESG performance, clustering standard errors at the county level is necessary. This adjustment helps mitigate estimation bias caused by inter-firm correlation, thereby ensuring the robustness and reliability of the study's conclusions. Column (1) and Column (3) of Table 5 present the results with standard errors clustered at the county level, showing that the coefficient for Insured remains significantly positive at the 1 % level. This finding confirms that the baseline regression results are robust and not sensitive to potential within-county correlations. In other words, the significance of the Insured coefficient is not driven by unobserved county-level factors, and the causal relationship between D&O liability insurance and ESG performance is not an artifact of underestimated standard errors or intra-county correlations.

Additionally, in some cases, the industry to which a firm belongs may have a systematic influence on its environmental performance, such as through the economic environment, regulatory policies, or the level of market competition within the industry. These

Table 5
Regression results clustered at different levels.

	(1)	(2)	(3)	(4)
	esgscore $_{t+1}$	esgscore $_{t+1}$	esggrade $_{t+1}$	esggrade $_{t+1}$
Insured	0.7816***	0.7816***	0.1370***	0.1370***
	(0.1634)	(0.1999)	(0.0309)	(0.0360)
lnsize	0.8132***	0.8132***	0.1763***	0.1763***
	(0.0724)	(0.0850)	(0.0138)	(0.0165)
lnage	0.4430	0.4430	0.0276	0.0276
	(0.5418)	(0.7522)	(0.1073)	(0.1369)
cash	0.0145***	0.0145***	0.0035***	0.0035***
	(0.0029)	(0.0032)	(0.0005)	(0.0006)
roa	0.0993***	0.0993***	0.0149***	0.0149***
	(0.0061)	(0.0061)	(0.0010)	(0.0011)
leverage	−0.0293***	−0.0293***	−0.0068***	−0.0068***
	(0.0032)	(0.0026)	(0.0006)	(0.0005)
soe	0.5793**	0.5793***	0.1040**	0.1040***
	(0.2330)	(0.2064)	(0.0430)	(0.0385)
lnboard	−0.0105	−0.0105	0.0233	0.0233
	(0.3062)	(0.2679)	(0.0582)	(0.0534)
dual	0.0374	0.0374	−0.0093	−0.0093
	(0.1003)	(0.0817)	(0.0190)	(0.0180)
top1	0.0090*	0.0090	0.0021**	0.0021*
	(0.0053)	(0.0056)	(0.0010)	(0.0012)
indep	0.0359***	0.0359***	0.0101***	0.0101***
	(0.0083)	(0.0079)	(0.0015)	(0.0014)
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Constant	60.0577***	60.0577***	1.3947***	1.3947***
	(2.0598)	(2.6633)	(0.4164)	(0.4774)
Observations	40,446	40,446	40,785	40,785
R-squared	0.5335	0.5335	0.5751	0.5751

Note: The (1st) and (3rd) columns represent the robust standard errors clustered at the county level; the (2nd) and (4th) columns represent the robust standard errors clustered at the industry level. ***p < 0.01, **p < 0.05, *p < 0.1.

factors can cause companies in the same industry to exhibit similar characteristics and behaviors. If the correlation between firms within the same industry is not considered, standard errors may also be underestimated. To address this, clustering standard errors at the industry level can effectively prevent underestimation of standard errors due to within-industry correlations. Column (2) and Column (4) of Table 5 show the results with standard errors clustered at the industry level, with the Insured coefficient remaining significantly positive at the 1 % level. This suggests that the effect of D&O liability insurance on corporate ESG performance is not dependent on shared industry characteristics, confirming that the baseline regression results are robust.

4.2.5. Instrumental variable regression

So far, all identification strategies have shown that D&O liability insurance significantly improves corporate ESG performance. However, we still worry that issues such as reverse causality and omitted variables may lead to biased baseline estimates. First, a company's ESG performance might, in turn, affect its decision to purchase D&O liability insurance. This is because companies with strong ESG performance often face higher public and regulatory expectations and may assume greater legal and reputational risks. To address these risks, companies may be more inclined to purchase D&O liability insurance to protect their executives from lawsuits or financial losses arising from fulfilling social responsibility, environmental protection, and governance obligations. This reverse causality could confuse the causal relationship in the estimates, preventing us from determining the true impact of D&O liability insurance on ESG performance. Secondly, certain unobserved factors in reality—such as managerial risk preferences or corporate culture—may simultaneously influence a company's decision to purchase D&O liability insurance and its ESG performance. If these variables are omitted and correlated with the decision to purchase D&O liability insurance, the estimates in the regression model may be biased.

To overcome these endogeneity issues and ensure the accuracy and credibility of the estimation results, we follow the approach used in existing research by selecting the D&O liability insurance coverage rate within the same year, city, and industry as an instrumental variable (IV) for the firm's decision to purchase D&O liability insurance. The selection of the IV is based on the theory of peer effects, which suggests that a firm's decisions are often influenced by the behavior of other firms in the same region or industry. For example, when most firms in an industry purchase D&O liability insurance, other firms are likely to follow suit due to peer pressure or a bandwagon effect. Hence, this coverage rate effectively explains a company's purchasing behavior and satisfies the relevance condition for the IV. Moreover, this coverage rate only indirectly affects a company's ESG performance by influencing its purchasing decision, ensuring it is unrelated to the error term in the ESG performance equation, thus meeting the exclusion restriction. By using this IV, we can more robustly identify the true impact of D&O liability insurance on a company's ESG performance and avoid estimation bias caused by endogeneity issues.

The IV estimation results are presented in Table 6. Column (1) reports the IV estimation of the impact of D&O liability insurance on the firm's overall ESG score. The results show that the Cragg-Donald Wald F-statistic is greater than 50, far exceeding the common

Table 6
Regression results using IV.

VARIABLES	(1)	(2)
	$esgscore_{t+1}$	$esggrade_{t+1}$
Insured	0.8174***	0.1402***
	(0.1339)	(0.0240)
lnsize	0.8125***	0.1762***
	(0.0454)	(0.0080)
lnage	0.4440*	0.0277
	(0.2623)	(0.0468)
cash	0.0145***	0.0035***
	(0.0021)	(0.0004)
roa	0.0993***	0.0149***
	(0.0033)	(0.0006)
leverage	−0.0293***	−0.0068***
	(0.0020)	(0.0004)
soe	0.5773***	0.1039***
	(0.1347)	(0.0240)
lnboard	−0.0118	0.0232
	(0.2092)	(0.0372)
dual	0.0373	−0.0093
	(0.0660)	(0.0117)
top1	0.0090***	0.0021***
	(0.0032)	(0.0006)
indep	0.0359***	0.0101***
	(0.0062)	(0.0011)
Year FE	Yes	Yes
Firm FE	Yes	Yes
Endogeneity test	0.6245	0.8046
Cragg-Donald Wald F statistic	>50	>50
R-squared	40,446	40,785
Observations	0.0551	0.0600

Note: Clustered robust standard errors at the firm level (in parentheses), ***p < 0.01, **p < 0.05, *p < 0.1.

threshold of 10, indicating that the chosen IV has a strong correlation with the endogenous variable (Insured), meaning it is not a weak IV. The Endogeneity test for endogeneity returns a p-value of 0.6245, suggesting we accept the null hypothesis of no endogeneity, meaning the baseline regression estimates do not suffer from significant endogeneity issues. We find that the estimated coefficient of Insured in Column (1) is 0.8174 and is significant at the 1 % level. This result is slightly higher than the baseline estimate of 0.7816, but the difference is not statistically significant. This indicates that the effect of directors' and officers' liability insurance in the instrumental variable regression did not significantly differ from the baseline regression results, further confirming the robustness of the estimates. Column (2) reports the IV regression results for the impact of D&O liability insurance on the firm's overall ESG rating. The Cragg-Donald Wald F-statistic is again significantly higher than 10, confirming that the chosen IV is not weak. Additionally, the Durbin-Wu-Hausman test for endogeneity produces a p-value of 0.8046, indicating that the IV-estimated coefficient for Insured does not significantly differ from the OLS-estimated coefficient, confirming that there is no significant endogeneity issue in the OLS regression. In conclusion, the baseline regression results are robust, and the use of the instrumental variable method did not lead to significant deviations in the results.

5. Mechanism identification

Previous empirical results have shown that D&O liability insurance significantly improves corporate ESG performance. This effect can be explained by the external oversight mechanism provided by D&O liability insurance. Not only does D&O liability insurance offer legal and financial protection to corporate management, but it also enables insurance companies to exert continuous monitoring over managerial actions, encouraging more prudent and responsible decision-making. This external oversight mechanism likely incentivizes management to implement improvements in several key areas, such as enhancing green innovation, adopting fintech solutions more broadly, and strengthening internal controls. These improvements contribute to reducing environmental, social, and governance (ESG) risks, thereby enhancing a company's overall ESG performance.

In this section, we aim to further identify the mechanisms through which D&O liability insurance exerts its positive effect on ESG performance. Specifically, from a theoretical perspective, D&O liability insurance influences corporate green innovation, fintech adoption, and internal controls through external oversight and litigation risk mitigation mechanisms. First, insurance companies, as external overseers, conduct continuous assessments and monitoring of management's behavior (O'Sullivan, 1997; Zou et al., 2008). This external pressure motivates management to prioritize compliance and risk management, thereby reducing opportunistic behavior and enhancing resource allocation toward green innovation and fintech adoption (Li et al., 2023; Lin & Lin, 2013). By promoting high-risk, long-term return projects, D&O liability insurance not only facilitates positive developments in green technology but also incentivizes companies to adopt fintech solutions to enhance operational efficiency. Moreover, by reducing the litigation risks faced by management, D&O liability insurance makes executives more willing to undertake the uncertainties and long-term investment risks associated with green innovation and fintech application (Yuan et al., 2016). The reduction of litigation risks enhances management's confidence in decision-making within complex market environments and strengthens internal control mechanisms, reducing internal control weaknesses caused by moral hazard (Chen & Keung, 2018). By alleviating managerial concerns, D&O liability insurance plays a pivotal role in encouraging management to actively pursue green innovation, adopt fintech solutions, and enhance internal controls, which ultimately enhances corporate ESG performance (Core, 1997; Li et al., 2023). To effectively identify the mechanisms through which D&O liability insurance impacts ESG performance, we construct the following three econometric models:

$$\text{greenino}_{t+1} = \beta_0 + \beta_1 Insured_{i,t} + \beta_2 Controls_{i,t} + \sum Firm_{i,t} + \sum Year_{i,t} + \varepsilon_{i,t} \quad (2)$$

$$\text{Infintech}_{t+1} = \beta_0 + \beta_1 Insured_{i,t} + \beta_2 Controls_{i,t} + \sum Firm_{i,t} + \sum Year_{i,t} + \varepsilon_{i,t} \quad (3)$$

$$\text{Incscore}_{t+1} = \beta_0 + \beta_1 Insured_{i,t} + \beta_2 Controls_{i,t} + \sum Firm_{i,t} + \sum Year_{i,t} + \varepsilon_{i,t} \quad (4)$$

In econometric equations (2)–(4), greenino_{t+1}, Infintech_{t+1} and Incscore_{t+1} represent the next period's levels of corporate green innovation, fintech application, and internal control quality, respectively. We measure corporate green innovation by the number of

Table 7
Regression results of mechanism identification.

	(1)	(2)	(3)
	greeninno_{t+1}	lnfintech_{t+1}	lncscore_{t+1}
Insured	2.1311***	0.0541***	0.0462**
	(0.3941)	(0.0179)	(0.0163)
Firm-level controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Constant	−43.4275***	1.1856***	5.1687***
	(3.5987)	(0.2154)	(0.3674)
Observations	41,703	41,720	40,893
R-squared	0.6883	0.8390	0.2573

Note: Clustered robust standard errors at the firm level (in parentheses), ***p < 0.01, **p < 0.05, *p < 0.1.

green invention and utility model patents filed by the company. The level of fintech application is measured using a text mining approach (Guo et al., 2024). Specifically, we extract the frequency of 124 fintech-related keywords from annual reports, covering six dimensions: artificial intelligence, blockchain, cloud computing, big data, online, and mobile technology (see Table A3 in Appendix). The frequency of these fintech keywords is then log-transformed to obtain the fintech development level for each firm in each year. The fintech index constructed based on text mining captures the specific characteristics of fintech adoption within firms and is better suited for firm-level microanalysis. The quality of internal control is measured using the Bodi Internal Control Index, where the firm's internal control score is log-transformed. We estimate econometric equations (2)–(4) using a panel data model with firm and year fixed effects to account for unobserved heterogeneity across firms and time.

Table 7 reports the regression results of mechanism identification. Column (1) shows the regression results of the effect of D&O liability insurance on corporate green innovation. The results indicate that the estimated coefficient of D&O liability insurance is 2.1311, which is statistically significant at the 1 % level. This suggests that purchasing D&O liability insurance significantly increases the average level of corporate green innovation by 39.04 % (2.1311/5.4586). This finding implies that D&O liability insurance, by reducing litigation risks and enhancing external monitoring pressure, encourages management to engage more actively in green innovation, ultimately improving corporate ESG performance.

Column (2) presents the regression results of the impact of D&O liability insurance on the level of fintech adoption. The coefficient estimate for D&O liability insurance is significantly positive at the 1 % level, indicating that D&O liability insurance may reduce management's litigation risks, making them more willing to bear uncertainties and investment risks associated with fintech applications. Moreover, as an external monitor, insurance companies' continuous oversight of corporate behavior may drive management to adopt advanced fintech tools more actively. These tools help firms manage resources more effectively, reduce environmental impact, and enhance the efficiency of fulfilling social responsibilities, thereby improving corporate ESG performance.

Column (3) shows the regression results of the impact of Directors and Officers (D&O) liability insurance on corporate internal control, indicating significance at the 5 % level but not at the 1 % level. Its positive effect is due to the fact that when providing D&O liability insurance, insurance companies conduct strict reviews of a firm's internal governance and risk management to assess potential compensation risks. This external supervision prompts corporate management to strengthen internal controls in order to reduce operational risks that could lead to insurance claims. Therefore, under this external pressure, firms must optimize their financial reporting, compliance management, and operational processes to meet the expectations of insurance companies and external investors, thereby enhancing the quality and effectiveness of internal control. However, this effect appears relatively moderate compared to the other two mechanism variables (green innovation and fintech). Theoretically, this may be attributed to the complexity and long-term nature of improving internal control. The enhancement of internal control systems requires considerable time and effort across multiple dimensions, including institutional building, personnel training, and process optimization. Consequently, its short-term effects may not be as direct or significant as those of green innovation and fintech. Moreover, differences in the foundational aspects and management levels of internal control among different firms may also result in varying degrees of influence from D&O liability insurance on their internal controls. Therefore, while D&O liability insurance has promoted improvements in corporate internal control to some extent, its mechanism of action is relatively complex and warrants further investigation.

6. Heterogeneity test

In this section, we examine the heterogeneous effects of D&O liability insurance on corporate ESG performance under different external environments (green finance) and internal characteristics (Industry Category, institutional investor ownership, and tax

Table 8
Regression results of heterogeneous effects.

VARIABLES	(1)	(2)	(3)	(4)
	$esgscore_{t+1}$	$esgscore_{t+1}$	$esgscore_{t+1}$	$esgscore_{t+1}$
Insured	0.5538***	0.9465***	0.6987***	0.7149***
	(0.1840)	(0.1762)	(0.1643)	(0.1184)
Insured × gfindex	3.5047***			
	(1.1601)			
Insured × Pollute		−0.7474**		
		(0.3648)		
Insured × Inshare			0.0104***	
			(0.0035)	
Insured × Taxpre				1.1477***
				(0.4009)
Firm-level controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Constant	59.9269***	60.0471***	59.7395***	59.9437***
	(1.7644)	(1.7595)	(1.7592)	(1.2057)
Observations	40,437	40,446	39,962	40,446
R-squared	0.5337	0.5337	0.5346	0.5337

Note: Clustered robust standard errors at the firm level (in parentheses), ***p < 0.01, **p < 0.05, *p < 0.1.

incentives). The specific results are shown in Table 8.

6.1. The role of green finance

The development of green finance provides firms with more opportunities for green financing and policy incentives. These financing channels are typically closely linked to sustainable development and ESG goals, encouraging firms to improve their ESG performance through green innovation and sustainable projects. D&O liability insurance, by mitigating legal and financial risks for management, gives them more confidence to undertake high-risk green projects. Therefore, in regions with a higher level of green finance development, firms can more easily access funds to promote green projects (Irfan et al., 2022; Yu et al., 2021), and D&O liability insurance further alleviates management's concerns over project failures or legal litigation (Lin & Lin, 2013), leading to better ESG performance.

To test the moderating effect of green finance on the relationship between D&O liability insurance and corporate ESG performance, we construct an interaction term between D&O liability insurance and regional green finance development (gfindex), and incorporate it into the baseline regression model. We use a two-way fixed-effects regression to estimate the results, which are reported in Column (1) of Table 8. The results show that the interaction term between D&O liability insurance and green finance development (Insured × gfindex) has a coefficient of 3.5047, which is statistically significant at the 1 % level. Specifically, this suggests that for every one-unit increase in the green finance index (gfindex), the effect of D&O liability insurance on ESG performance increases by approximately 4.79 % (3.5047/73.15) relative to the baseline effect. This finding indicates that in regions with higher green finance development, the positive impact of D&O liability insurance on corporate ESG performance is stronger and more significant (the specific estimation results are shown in Figure A3 in Appendix).

6.2. The role of industry category

Heavily polluting enterprises are typically under strict scrutiny from the government, environmental organizations, and the public, so their improvements in ESG performance are often driven by mandatory regulations, leaving less room for managerial discretion (Guo et al., 2023; Kassinis & Vafeas, 2006). In such cases, the role of D&O liability insurance is relatively limited, as ESG improvements in heavily polluting firms are mainly to meet compliance requirements rather than a proactive pursuit of higher social responsibility (Matisoff et al., 2013). In contrast, non-polluting firms face less external regulatory pressure, and their ESG improvements rely more on management's autonomy and discretion (Hawn & Ioannou, 2016). In this context, D&O liability insurance, through external supervision and risk assessments provided by insurance companies, creates a supplementary soft constraint mechanism that encourages management to focus more on improving environmental, social, and governance practices (Core, 1997; O'Sullivan, 1997). D&O liability insurance not only alleviates concerns about legal and financial risks associated with advancing ESG projects but also provides external reference standards, further enhancing management's self-regulation and proactive efforts in ESG improvements.

Thus, in non-polluting firms, D&O liability insurance more effectively promotes ESG performance by complementing external oversight. To examine the moderating effect of industry category on the relationship between D&O liability insurance and corporate ESG performance, we construct an interaction term between D&O liability insurance and industry category (Pollute) and incorporate it into the baseline regression model. We use a two-way fixed-effects regression for estimation, and the results are reported in Column (2) of Table 8. The results show that the coefficient of the interaction term between D&O liability insurance and industry category (Insured × Pollute) is −0.7474, and it is significant at the 5 % level. Although this result is not as strong as other effects, it still indicates that when a company is in a heavily polluting industry, the positive impact of D&O liability insurance on corporate ESG performance is significantly weaker (specific estimation results are shown in Figure A4 in Appendix).

6.3. The role of institutional ownership

Institutional investors typically have long-term investment objectives and are more focused on corporate sustainability, encouraging management to implement ESG strategies that align with the firm's long-term interests, thereby improving corporate ESG performance (Liu et al., 2023; Wang et al., 2023). Generally, institutional investors with larger ownership stakes are more likely to influence the company through voting, questioning, board appointments, and ongoing monitoring, ensuring that corporate strategy aligns with their long-term interests. This external monitoring mechanism directs firms to prioritize sustainability goals (Pucheta-Martínez & Chiva-Ortells, 2018), ultimately leading to better ESG performance.

While institutional investors with significant ownership stakes are more likely to engage in corporate governance and promote ESG performance, most ESG projects have long timelines and involve high uncertainty and risk. These projects often deal with complex environmental and social factors that are subject to long-term policy changes and technological developments (Oliver Yébenes, 2024). Moreover, ESG investments require substantial upfront capital, and although they may generate returns in the long run, management often faces greater financial pressure and market risks in the short term (Chopra et al., 2024). According to agency theory, managers tend to avoid high-risk, long-term projects like ESG initiatives, opting instead for projects that offer quicker returns with lower risk. However, D&O liability insurance provides legal protection to managers, mitigating their risk of lawsuits or personal liability in case of failure or poor decision-making in ESG projects. This risk transfer mechanism alleviates some of the concerns that may lead managers to make overly conservative decisions.

Thus, the external monitoring effect of long-term institutional ownership complements the risk transfer mechanism provided by D&O liability insurance, which together help drive improvements in ESG performance. As institutional ownership increases, the

positive impact of D&O liability insurance on corporate ESG performance becomes more pronounced. To examine the moderating effect of institutional ownership on the relationship between D&O liability insurance and corporate ESG performance, we introduce the variable of long-term institutional investor shareholding ratio, which is determined by calculating the average turnover rate of institutional investors over the past year. Based on this, we construct an interaction term between D&O liability insurance and long-term institutional ownership (Inshare) and incorporate it into the baseline regression model. We use a two-way fixed-effects regression for estimation, and the results are reported in Column (3) of Table 8. The results show that the interaction term between D&O liability insurance and long-term institutional ownership (Insured × Inshare) has a coefficient of 0.0104, which is statistically significant at the 1 % level. This finding indicates that as long-term institutional ownership increases, the positive impact of D&O liability insurance on corporate ESG performance becomes increasingly significant (the specific estimation results are shown in Figure A5 in Appendix).

6.4. The role of tax incentives

Typically, ESG projects involve significant upfront investments and long payback periods, which can impose financial pressure on companies. However, tax incentives not only provide additional financial support and alleviate financing constraints (Huang et al., 2024), but also send positive signals to the market and stakeholders, enhancing the company's reputation and boosting shareholder confidence. This, in turn, helps firms secure more long-term capital, enabling them to adequately fund their ESG initiatives, thereby improving ESG performance (Huang et al., 2024). Although tax incentives provide financial backing for ESG projects, management may still lack sufficient motivation to implement these projects due to their inherent uncertainty and high risk. Specifically, ESG projects carry the risk of missteps, which may lead to accountability and legal liabilities, making management more cautious about undertaking such initiatives. However, D&O liability insurance, as a risk transfer mechanism, effectively mitigates the legal and financial risks associated with potential ESG project failures. This protection allows management to proceed with ESG projects more confidently. In this context, D&O liability insurance and tax incentives work complementarily to improve corporate ESG performance. As the level of tax incentives increases, the positive impact of D&O liability insurance on corporate ESG performance becomes stronger.

To test the moderating effect of tax incentives on the relationship between D&O liability insurance and corporate ESG performance, we construct an interaction term between D&O liability insurance and tax incentives (Insured × Taxpre) and include it in the baseline regression model. We estimate the model using a two-way fixed-effects regression, with the results reported in Column (4) of Table 8. The results show that the coefficient of the interaction term between D&O liability insurance and tax incentives is 1.1477, which is statistically significant at the 1 % level. This finding indicates that as the level of tax incentives increases, the positive effect of D&O liability insurance on corporate ESG performance becomes more pronounced (the specific estimation results are shown in Figure A6 in Appendix).

6.5. The role of COVID-19

As a significant global external shock, the COVID-19 pandemic has profound implications for business operating environments, risk management strategies, and long-term development plans (Golubeva, 2021). According to risk management theory (Nocco & Stulz, 2006), the heightened uncertainty and economic volatility brought about by the pandemic have markedly increased operational and financial pressures on enterprises, leading to subpar performance (Zheng, 2022). This situation compelled management to concentrate more resources on short-term survival and profitability goals rather than long-term sustainable development projects such as ESG initiatives. This short-term-oriented decision-making could undermine the incentive effect of D&O liability insurance on corporate ESG performance. Moreover, agency theory (Meckling & Jensen, 1976) posits that D&O liability insurance encourages executives to engage in long-term investments and ESG-related decisions by mitigating their legal liability risks. However, during the pandemic, with

Table 9
Effects of D&O liability insurance by COVID-2019.

VARIABLES	(1)	(2)
	pre-COVID	COVID
	$esgscore_{t+1}$	$esgscore_{t+1}$
Insured	1.0505***	0.3681***
	(0.3416)	(0.1260)
Firm-level controls	Yes	Yes
Firm FE	Yes	Yes
Year FE	Yes	Yes
Constant	61.4090***	63.3428***
	(2.2870)	(5.1098)
Observations	27,963	12,187
R-squared	0.6038	0.8546

Note: Clustered robust standard errors at the firm level (in parentheses), ***p < 0.01, **p < 0.05, *p < 0.1. Using the bdiff command in Stata, we test the significance of the difference in the coefficient of Insured between the two groups. The results show that the difference in the coefficient of Insured between the two groups is 0.682 and is statistically significant at the 5 % level.

stakeholders focusing more on financial stability and short-term performance, executives might reduce investment in ESG projects (Huang et al., 2024). Meanwhile, the pandemic may have lessened external regulatory pressures, diminishing the legal and reputational risks associated with poor ESG performance and further weakening the positive incentive effects of D&O liability insurance on ESG outcomes (Core, 1997). Therefore, investigating the differential impact of D&O liability insurance on corporate ESG performance before and after the COVID-19 outbreak not only aids in understanding how external shocks moderate corporate governance mechanisms but also provides policymakers with insights into optimizing corporate governance and ESG performance under crisis conditions.

Based on this theoretical background, we divided our sample into two periods: pre-COVID-19 (up to and including 2019) and during the COVID-19 pandemic (from 2020 onwards), to separately examine the influence of D&O liability insurance on corporate ESG performance. This division allows us to more clearly identify how the pandemic moderates corporate governance mechanisms and ESG performance. Specifically, we conducted regression analyses using a dual fixed-effects model on the two subsamples and compared the coefficients of D&O liability insurance before and after the pandemi

The regression results, presented in Table 9, show that prior to the pandemic, the coefficient of D&O liability insurance on corporate ESG performance was 1.0505, significant at the 1 % level, indicating a significant enhancement of ESG performance by D&O liability insurance before the pandemic. During the pandemic, however, the coefficient decreased to 0.3681, which, although still significant, indicates a notable reduction in the positive impact on ESG performance. Using the bdiff command in Stata to test the significance of the difference between these two coefficients, we found the difference to be 0.682, significant at the 5 % level. These findings suggest that the pandemic significantly weakened the positive effect of D&O liability insurance on corporate ESG performance.

This finding aligns with predictions from risk management and agency theories. Under pandemic-induced uncertainties and financial pressures, management may prioritize resources for short-term survival over long-term ESG projects. Furthermore, reduced external regulatory pressure and lower legal risks during the pandemic likely diminished the incentive effect of D&O liability insurance on executive ESG decision-making. These results not only highlight the moderating role of external shocks on corporate governance mechanisms but also provide crucial insights for policymakers, suggesting that strengthening external oversight and incentive mechanisms is essential for ensuring companies can pursue long-term sustainable development goals while addressing immediate challenges during crises.

7. Conclusion and policy implications

This study is based on panel data from Chinese A-share listed companies from 2009 to 2023 and employs econometric methods such as the fixed effects model, year-by-year propensity score matching (PSM), and instrumental variable regression (IV) to examine the impact of D&O liability insurance on corporate ESG performance and its underlying mechanisms. The key findings are as follows:

First, D&O liability insurance significantly improves corporate ESG performance, suggesting that it is not merely a legal risk mitigation tool but also an external governance mechanism that optimizes corporate governance and enhances long-term sustainable competitiveness. Through external oversight, liability constraints, and risk transfer, D&O insurance incentivizes management to actively fulfill environmental responsibilities (E), strengthen social responsibility (S), and optimize governance structures (G), thereby enhancing overall ESG performance. This conclusion remains robust after a series of robustness tests, including alternative dependent variable measurements, year-by-year PSM, placebo tests, and instrumental variable regression.

Second, D&O insurance primarily enhances ESG performance through three key mechanisms: promoting green innovation, advancing financial technology adoption, and improving internal control systems. Green innovation benefits from reduced legal and financial concerns associated with long-term, high-risk ESG investments, encouraging greater corporate investment in clean technology and green products. This, in turn, strengthens firms' capabilities in environmental protection, sustainable resource utilization, and social responsibility fulfillment. The adoption of financial technology contributes by improving ESG data transparency and regulatory compliance, optimizing resource allocation efficiency, and enhancing firms' competitiveness in the digital era. Additionally, D&O insurance reinforces compliance oversight and managerial accountability, fostering improvements in corporate internal control systems. However, given that internal control enhancement requires institutional reform, cultural shifts, and long-term governance changes, its impact on ESG performance tends to be gradual, with relatively moderate short-term effects.

Finally, the impact of D&O insurance on ESG performance exhibits significant heterogeneity across different market environments and industry characteristics. In markets with well-developed green finance systems, a high proportion of institutional investors, and strong tax incentives, D&O insurance exerts a more pronounced positive effect on ESG performance, demonstrating that sound financial support and market supervision amplify its governance effectiveness. However, in heavily polluting industries, where compliance costs are higher and regulatory pressures more intense, the positive impact of D&O insurance on ESG performance is somewhat constrained, highlighting the limitations of external governance tools in such sectors. Furthermore, external shocks may also influence the ESG-enhancing effect of D&O insurance. For instance, during the COVID-19 pandemic, firms prioritized short-term survival over ESG objectives, thereby weakening the role of D&O insurance in ESG performance improvement. This finding suggests that under extreme uncertainty, firms may adjust their sustainability commitments due to resource constraints and external pressures, affecting the effectiveness of D&O insurance as a governance tool.

Based on these findings, the following policy recommendations are proposed: First, regulatory authorities should mandate that listed companies disclose their D&O insurance coverage as part of ESG reporting and encourage rating agencies to incorporate this information into ESG assessment frameworks. This would enhance capital markets' recognition of firms' long-term sustainability. Meanwhile, governments could facilitate the development of "ESG liability insurance" or "green D&O insurance" products by insurers.

Companies with superior ESG performance could be offered discounted premiums, while firms with poor ESG compliance could face stricter risk assessments, thereby strengthening the market-driven governance function of D&O insurance.

Second, D&O insurance should be integrated with green financial instruments to amplify its positive impact on ESG performance. Policymakers could establish a "D&O Insurance + Green Credit" linkage, requiring financial institutions to consider firms' D&O insurance coverage as a factor in ESG performance evaluations during loan approvals, thus providing better financing conditions for companies with strong ESG performance. In addition, green bond issuers could be encouraged to incorporate D&O insurance coverage as a credit rating indicator to enhance transparency and attractiveness in the green bond market. Furthermore, the government could set up an "ESG Insurance Support Fund" to provide financial support to firms that purchase D&O insurance and actively engage in ESG initiatives, ensuring stable long-term funding for corporate sustainability efforts. For heavily polluting industries, where compliance costs are high and regulatory constraints are stricter, D&O insurance's effectiveness in promoting ESG performance is relatively limited. Therefore, targeted policies should be implemented. The government could introduce "High-Pollution Industry ESG Liability Insurance", requiring firms to undergo more rigorous ESG audits when purchasing D&O insurance and mandating the establishment of ESG improvement plans to ensure that sustainability strategies are continually optimized under insurance oversight. Additionally, tax incentives or green subsidies could be provided to high-pollution firms that demonstrate strong ESG performance, encouraging them to adopt more stringent ESG liability insurance policies and accelerating their transition toward greener business practices.

Moreover, firms' awareness of D&O insurance's role in ESG performance management should be enhanced to improve market recognition. Regulatory agencies, in collaboration with industry associations and insurance companies, should conduct training programs for corporate executives on the governance benefits of D&O insurance and encourage firms to actively integrate it into their ESG management strategies. Furthermore, the government could collect and publish case studies demonstrating the positive impact of D&O insurance on ESG performance, establishing an ESG Insurance Case Repository to share best practices and promote broader adoption of ESG liability insurance in the market.

Finally, the governance effectiveness of D&O insurance may be affected by global crises such as the COVID-19 pandemic. Therefore, a dynamic evaluation mechanism should be established to ensure its stability in uncertain environments. The government could set up an "ESG Insurance Emergency Fund" to provide temporary insurance subsidies to firms with strong ESG performance during periods of economic distress, preventing sustainability objectives from being deprioritized due to financial pressures. Additionally, insurers could conduct ESG insurance stress tests periodically to adjust premiums and coverage conditions based on evolving market conditions, thereby improving the resilience and adaptability of insurance mechanisms. Furthermore, policymakers should foster international cooperation on ESG insurance policies by developing a Global ESG Insurance Recognition Framework, strengthening the role of D&O insurance in corporate sustainability governance on a global scale and further enhancing ESG performance worldwide.

Despite systematically revealing the positive impact of D&O liability insurance on corporate ESG performance and its underlying mechanisms, this study has certain limitations that warrant further exploration. First, the data primarily derive from Chinese A-share listed companies. While this market is representative in terms of corporate governance structure, legal environment, and capital market development, substantial differences exist across countries and regions regarding regulatory frameworks, investor preferences, and ESG development stages. As a result, the generalizability of the findings requires further validation in broader international contexts. Second, the measurement of ESG performance relies on existing rating systems. Although these systems are widely adopted in academic research and practice, their methodologies, weighting schemes, and data availability may still constrain a comprehensive assessment of corporate sustainability efforts. Furthermore, this study primarily examines the impact of D&O liability insurance on ESG performance through the channels of green innovation, fintech adoption, and internal control quality, yet it does not fully explore other potential mechanisms, such as corporate culture, stakeholder pressure, corporate social responsibility strategies, and policy incentives. These moderating factors present opportunities for future research. Therefore, future studies could enhance the robustness of these findings by testing them in cross-national settings, incorporating more comprehensive ESG assessment dimensions, and exploring more intricate causal mechanisms to deepen our understanding of how D&O liability insurance influences corporate sustainability.

Credit author statement

Houjian Li: Data Collection, Methodology, Software, Formal analysis, Reviewing and Editing, Writing-Original draft preparation. Quanfeixue Cheng: Methodology, Writing- Reviewing and Editing, Writing-Original draft preparation.Mengying Su: Data curation, Formal analysis, Methodology, Software, Writing – review & editing.Kuan Zhang: Conceptualization, Data Collection, Methodology, Reviewing and Editing.

Appendix

Table A1
Sample distribution by year

(*continued on next page*)

Table A1 (*continued*)

Year	Freq.	Percent	Cum.
Year	Freq.	Percent	Cum.
2009	1297	3.21	3.21
2010	1443	3.57	6.77
2011	1778	4.39	11.17
2012	2046	5.06	16.22
2013	2202	5.44	21.66
2014	2262	5.59	27.25
2015	2331	5.76	33.01
2016	2474	6.11	39.13
2017	2745	6.79	45.91
2018	3111	7.69	53.60
2019	3138	7.76	61.36
2020	3318	8.2	69.56
2021	3765	9.3	78.86
2022	4236	10.47	89.33
2023	4300	10.63	100.00
Total	40,446	100.00	

Table A2
Variable definitions

Variable	definitions
$esgscore_{t+1}$	The ESG composite score of the firm for the following year, sourced from the Huazheng database.
$esggrade_{t+1}$	The ESG composite rating of the firm for the following year, sourced from the Huazheng database.
ESG_pengbo_{t+1}	The ESG composite score of the firm for the following year, sourced from the Bloomberg database.
Insured	Indicates whether the firm has purchased Directors and Officers (D&O) liability insurance. Yes = 1, No = 0, sourced from the CNRDS database.
gfindex	The green finance development index of the city-level municipality where the firm is located.
Pollute	Indicates whether the firm belongs to a high-pollution industry. Yes = 1, No = 0, sourced from the CSMAR database.
Inshare	The proportion of long-term institutional ownership (%), sourced from the CNRDS database.
taxpre	The firm's tax preference ratio, representing the proportion of tax exemptions and rebates received by the firm, sourced from the CSMAR database.
greeninno	The number of green inventions and utility model patents the firm applied for in the given year, sourced from the CNRDS database.
lnfintech	The firm's financial technology innovation level, measured using text analysis.
lncscore	The natural logarithm of the firm's internal control quality score, sourced from the Bodi Internal Control Index.
lnsize	The natural logarithm of the firm's total assets.
lnage	The natural logarithm of the firm's age (firm age).
cash	The firm's cash holdings, calculated as (monetary funds + tradable financial assets)/total assets (%).
roa	The firm's return on total assets (%).
leverage	The firm's total debt ratio, calculated as total liabilities/total assets (%).
lnboard	The natural logarithm of the total number of board members.
dual	Indicates whether the chairman also serves as the CEO. Yes = 1, No = 0.
top1	The shareholding ratio of the largest circulating shareholder (%).
indep	The proportion of independent directors to the total number of directors (%).
soe	Indicates whether the firm is a state-owned enterprise. Yes = 1, No = 0.

Table A3
Fintech keyword library

Dimension	Fintech keywords
Artificial Intelligence	Artificial intelligence, robotics, machine learning, deep learning, neural networks, facial recognition, biometric recognition, voice recognition, pattern recognition, image recognition, facial payment, virtual reality, augmented reality, knowledge graph, smart, smart deposits, smart counters, smart finance, smart branches, smart credit, intelligent, intelligent banking, smart marketing, intelligent, intelligent risk control, intelligent finance, automation, and natural language processing.
Blockchain	Blockchain, distributed ledger, supply chain, Internet of Things, near-field communication, quantum, quantum communication, data encryption, digital currency, and electronic currency.
Cloud Computing	Distributed, distributed storage, distributed computing, distributed architecture, distributed database, financial cloud, trusted computing, cloud adoption, private cloud, virtualization, privacy computing, cloud, cloud services, cloud service platform, cloudification, cloud computing, cloud architecture, cloud platform, cloud system, and cloud disaster recovery.
Big Data	Big data, big data analysis, big data services, big data technology, big data models, big data mining, data warehouse, data technology, data models, data mining, data governance, data center, digitization, digital transformation, digital finance, digital signature, digital ecosystem, digital credit card, digital bank, and digital marketing.
Online	E-commerce, electronic, electronic finance, electronic channels, e-commerce, e-banking, e-payment, Internet, Internet finance, fintech, digital technology, networking, Internet finance, online financial management, online financing, online consumer loans, online banking, online payment, online transactions, online banking, and online payment.
Mobile	Scenario-based finance, open platform, open banking, platformization, SDK (software development kit), mobile banking, mobile payments, barcode payments, mobile e-commerce, mobile Internet, mobile finance, mobile banking, mobile payments, digital payments, API (application programming interface), and direct sales bank.

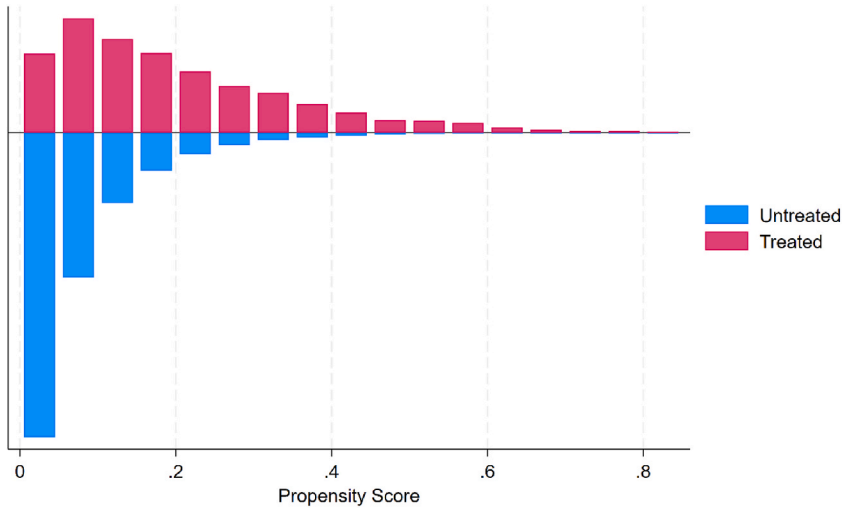

Fig. A1. Common support area.

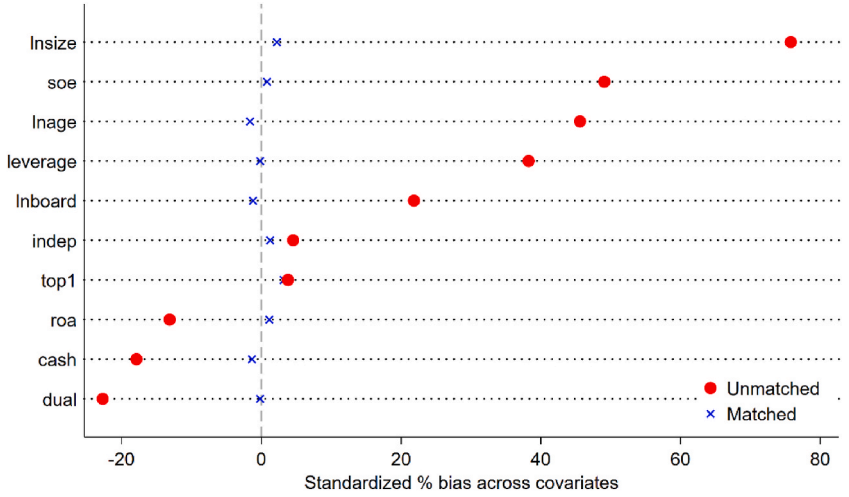

Fig. A2. Bias reduction effect before and after matching.

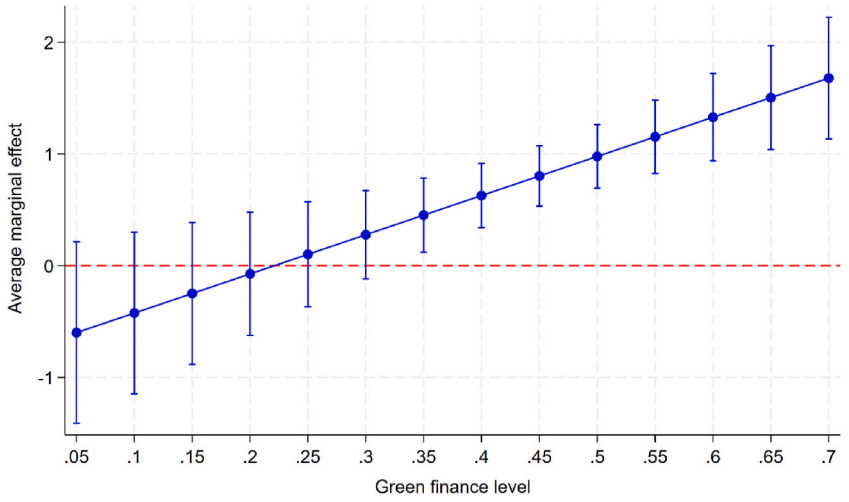

Fig. A3. The role of green finance.

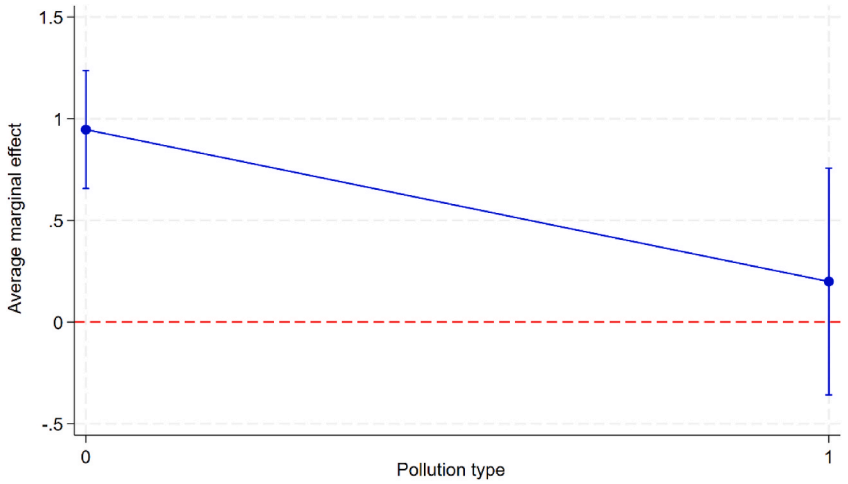

Fig. A4. The role of industry category.

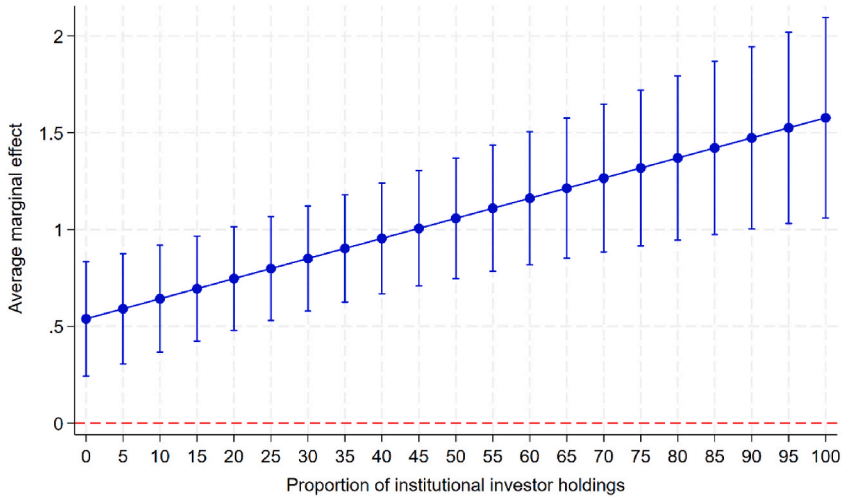

Fig. A5. The role of institutional investors.

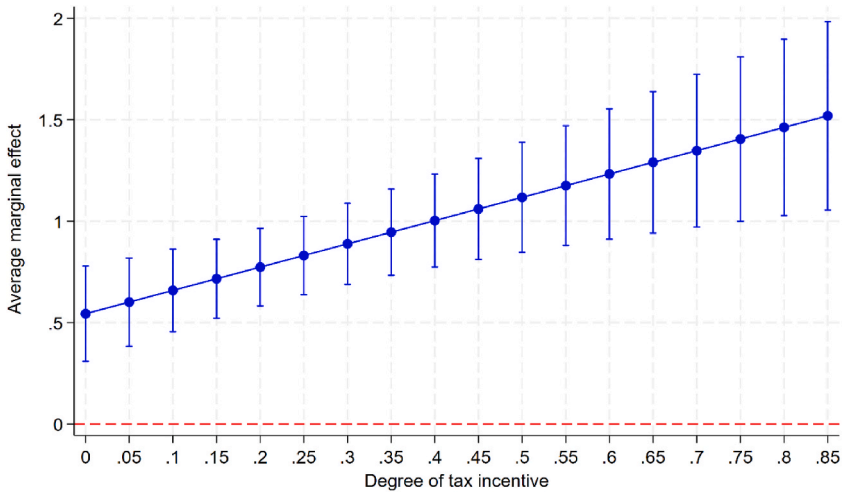

Fig. A6. The role of tax incentives.

Data availability

The authors do not have permission to share data.

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