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How does directors' and officers' liability insurance affect green innovation? Evidence from China

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ABSTRACT

This paper examines the relationship between directors' and officers' liability insurance (D&O insurance) and firms' green innovation. Using a large dataset on firms' green innovation achievements of Chinese listed firms over 2002–2019, we show that firms with D&O insurance significantly boost their green innovation performance, particularly those facing higher litigation risks, without political connections, and exhibiting corporate governance. Additionally, we find that the green innovation of insured firms significantly bolsters firm value, indicating that D&O insurance helps achieve a win-win situation between shareholder value and environmental sustainability. The mechanism analysis shows that the supervision effect of D&O insurers in mitigating managerial self-interest behavior is the underlying channel through which D&O Insurance affects firms' green innovation. Overall, our findings suggest that D&O insurance encourages firms' directors and officers to actively pursue green innovation, thereby positively impacting firm value.

1. Introduction

Directors' and officers' liability insurance (hereafter D&O insurance) is a common policy provided by firms to their directors and officers aimed at protecting their personal assets from litigation. While a long line of studies has examined various issues related to D&O insurance, little attention has been paid to whether and how the insurance affects sustainable development. Given that green innovation, involving developing new ideas, behaviors, products, and processes, has been considered an effective way to ease the burden of the environment and advance sustainable development (e.g., Du & Li, 2019; Jin et al., 2019; Liu & Kong, 2021; Singh et al., 2020), this study examines whether and how D&O insurance affects green innovation.

The impact of D&O insurance on green innovation is unclear. On the one hand, D&O insurance introduces the supervision of D&O insurers on the managerial self-interest behavior (Core, 2000; Holderness, 1990), which helps improve the allocation efficiency of

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green innovation resources, thereby promoting firms' green innovation. On the other hand, by isolating managers' personal wealth from the consequences of their own decisions, D&O insurance may encourage the management to adopt a self-serving behavior, such as consuming private benefits and misusing corporate resources (Chalmers et al., 2002), which negatively influences firms' green innovation projects.

We study this empirical issue in China because the U.S. does not require firms to disclose D&O insurance data (Chung et al., 2015); thus, this data is unavailable for U.S. firms (Chung & Wynn, 2008). In China, however, D&O insurance information is mandatorily disclosed and thus publicly available. Moreover, the green innovation professional database offered by the Chinese Research Data Services Platform (CNRDS) provides rich, detailed, and updated information about Chinese-A-share listed firms' green innovation.

Using a large sample of Chinese A-share listed companies between 2002 and 2019, where the information on D&O insurance purchases was disclosed, we find that, ceteris paribus, compared with uninsured firms, firms purchasing D&O insurance achieve better green innovation performance. We use the propensity score matching (PSM) methodology, the entropy balancing approach, Heckman's two-stage method, and the fixed effects model to address the endogeneity concern that firms' decisions to purchase D&O insurance may be affected by omitted variable bias.

In addition, we conduct cross-sectional analyses to examine how heterogeneous factors, including firms' litigation risk, firms' political connections (PCs), and corporate governance, affect the relationship between D&O insurance and firms' green innovation. Specifically, first, we find that the positive impact of D&O insurance on green innovation is more pronounced for firms with higher litigation risk, supporting that D&O insurance encourages green innovation by easing the litigation concern of directors and officers. Second, we find that compared with firms without PCs, the positive effect of D&O insurance is less pronounced for firms with political connections, as political connections help protect listed firms from litigations (Jia et al., 2019), and firms with political connections have lower litigation risks. Third, D&O insurance reduces the disciplining effect of shareholder litigation for irresponsible management behaviors (Baker & Griffith, 2010), which may embolden managers to expropriate corporate resources and have a negative impact on green innovation. Since strong corporate governance constrains managers' self-interested behaviors, we expect that the positive effect of D&O insurance on green innovation is more pronounced for firms with better corporate governance. Consistent with our prediction, we reveal that insured firms achieve better green innovation performance when they have more institutional shareholdings or analysts' followings. We further document that insured firms' green innovation performance significantly advances firm value, implying that D&O insurance helps achieve a win-win situation between shareholder value and the environment. Further mechanism analysis shows that the supervision effect of D&O insurers on the managerial self-interest behavior is the underlying channel through which D&O Insurance affects firms' green innovation.

The literature most closely related to our study is Zhang et al.'s (2023) work. Our paper differs from Zhang et al. (2023) in the following aspects. First, as noted by Zhang et al. (2023), their study focuses on the interplay among D&O insurance, environmental regulation, and firms' environmental responsibility-taking. In contrast, our study primarily explores the impact of D&O insurance on green innovation. Specifically, we investigate (1) whether D&O insurance enhances firms' green innovation performance; (2) how various heterogeneous factors, such as firms' litigation risk, political connections, and corporate governance, influence the relationship between D&O insurance and firms' green innovation; and (3) whether companies that acquire D&O insurance experience improved firm value alongside enhanced green innovation performance. Although Zhang et al. (2023) have reported some findings akin to ours, such as insured firms significantly promoting firms' green innovation achievement, our study unveils several unexplored facets. Specifically, we find that (1) the positive impact of D&O insurance on green innovation is more pronounced for firms exposed to heightened litigation risk and those lacking political connections; (2) the external oversight by D&O insurance on managerial self-interest serves as the underlying channel through which D&O insurance affects green innovation; and (3) the green innovation performance of insured firms notably enhances firm value, exemplifying a win-win scenario between shareholder value and environmental concerns, among other results.

Second, Zhang et al. (2023) primarily center their paper on environmental regulation, delving into the role of such regulation in the nexus between D&O insurance and firms' environmental responsibility-taking. They explore this relationship through two lenses: the incentive effect of environmental regulation on firms' environmental responsibility-taking and the punitive effect of environmental regulation on firms' environmental pollution. In contrast, our focus is on the external supervision effect of D&O insurance, specifically examining how it intricately influences firms' green innovation. Our findings elucidate that the supervisory role of D&O insurers in curbing managerial self-interest behavior serves as the fundamental pathway through which D&O insurance impacts firms' green innovation.

Third, based on the litigation risk protection provided by D&O insurance, we have conducted heterogeneity analyses distinct from Zhang et al. (2023). For example, risk-averse managers often shy away from engaging in high-risk green innovation activities due to concerns about potential litigation. In this case, as opposed to firms in regions with low litigation risk, managers of firms in regions with high litigation risk are more likely to engage in green innovation activities as a result of D&O insurance easing their litigation concerns. Consistent with our expectation, the results indicate that the effect of D&O insurance on firms' green innovation is more pronounced for firms facing elevated litigation risks. In summary, our study extends beyond the scope of Zhang et al. (2023) by thoroughly examining the broader impact of D&O insurance on firms' green innovation.

We contribute to prior research in several ways. First, we enhance the literature concerning the consequences of D&O insurance on environmental achievement by investigating its impact on green innovation. Prior research has mainly focused on the influence of D&O insurance on accounting restatements (Weng et al., 2017), earnings conservatism (Chung & Wynn, 2008), cost of equity (Chen et al., 2016), debt financing (Lin et al., 2013), audit pricing (Chung et al., 2015), auditor choice (Chi & Weng, 2014), operating activities (Lin et al., 2019), acquisition activities (Lin et al., 2011) and firms' environmental responsibility-taking (Zhang et al., 2023). Unlike the existing literature, our study offers a comprehensive examination of how D&O insurance influences firms' green innovation

from a broader perspective. This approach not only enriches the literature on the economic implications of D&O insurance but also extends the findings of Zhang et al. (2023).

Second, we enrich prior literature on the determinants of green innovation from the corporate governance view (e.g., Amore & Bennedsen, 2016). Different from prior studies investigating the effect of government regulation or tax policy (Borsatto & Amui, 2019; Huang et al., 2019; Peng, 2020; Stucki et al., 2018) and corporate strategy (Liu & Kong, 2021) on firms' efforts on green innovation, our research examines the effect of D&O insurance purchases on firms' green innovation and provide evidence that D&O insurance improves firms' achievements in green innovation.

Finally, our study also has normative implications for regulators and practitioners. China, as the world's largest emerging economy, faces the challenge of reconciling environmental concerns with economic development. Our findings indicate that D&O insurance offers a means to harmonize these objectives, as evidenced by the creation of a win-win scenario between shareholder value and environmental sustainability. This suggests that policymakers may contemplate and promote D&O insurance as a mechanism to enhance firms' environmental performance. For instance, the government could consider implementing a mandatory environmental liability insurance system to incentivize firms to prioritize environmental performance efforts.

The rest of the paper proceeds as follows. Section 2 reviews the institutional background and related literature and develops our hypotheses. Section 3 describes the sample, data, and empirical model. Section 4 presents the main findings. Sections 5 and 6 further discuss robust checks and additional analyses, respectively. Section 7 concludes.

2. Institutional background and hypotheses development

2.1. Institutional background

D&O insurance was born in the United States at the beginning of the 20th century and was purchased by firms to cover the legal liability arising from their directors' and officers' professional activities on behalf of the company. In 1933, the Securities Act of the United States established the civil compensation system, which made it possible for shareholders to sue firms' directors and officers and led to a sharp increase in the professional risk of US-listed firms' managers. Subsequently, with the exposure of a series of financial scandals on Wall Street, D&O insurance gradually prevailed in developed capital markets such as Europe, America, and Japan and became the primary tool for enterprises and managers to avoid risks. D&O insurance is widespread among listed firms in common-law jurisdictions, such as Canada, the U.S., and the U.K. (Yuan et al., 2016; Zou et al., 2008). According to a survey covering 2059 American and Canadian companies conducted by Tillinghast Towers Perrin in 2014, 96% of the American and 88% of the Canadian firms purchased D&O insurance.

Compared to Western developed economies, the adoption of D&O insurance started in China occurred late. In 2002, the Supreme People's Court in China issued the "Notice on Issues Related to the Acceptance of Civil Tort Disputes Caused by False Statements in the Securities Market," which enables shareholders to take civil action within China. Following this directive, several major domestic property insurance companies successively launched D&O insurance. Notably, in 2002, Vanke Co., Ltd. became the first entity in China to purchase D&O insurance for its chairman, Mr. Wang Shi. The momentum continued in 2014, with the issuance of "Several Opinions on Accelerating the Development of Modern Insurance Service Industry" by the State Council of China, further promoting the expansion of D&O insurance in the country. Although the litigation risk and the adoption rate of D&O insurance in China are relatively low compared to those in developed capital markets, there is an increasing awareness among Chinese firms of the risks they face and the necessity for such insurance[1] (Hu et al., 2019).

In recent years, with the continual refinement of Chinese laws and regulations alongside the ongoing evolution of China's capital market, there has been a notable increase in shareholders' awareness of safeguarding their rights and directors' and senior management's cognizance of risk management. Consequently, D&O insurance has experienced rapid growth in China. This was particularly significant following the enactment of China's new Securities Law, officially implemented on March 1, 2020, which substantially heightened the costs of violations and litigation risks for directors, supervisors, and senior executives of listed companies. The financial fraud case involving Kangmei Pharmaceutical Co., Ltd., which incurred a high compensation penalty of up to RMB 2.459 billion, further intensified concerns among directors and executives of listed companies regarding their duty performance risks, thus stimulating a surge in demand for D&O insurance. Data from the Chinese Research Data Service Platform (CNRDS) reveals a remarkable increase in the number of listed companies purchasing D&O insurance from 317 to 1385 between 2019 and 2021, reflecting a staggering 336.9% rise within the first two years following the official implementation of China's new Securities Law. This underscores the substantial potential growth in D&O insurance coverage for Chinese-listed companies (Hu et al., 2019). The purchase of D&O insurance and its economic consequences have attracted wide attention from all circles. Existing literature also documents the positive role D&O insurance plays in the corporate governance of Chinese-listed firms (Yuan et al., 2016).

[1] In 2011, GAC Changfeng Automobile Co., Ltd. (600991) announced it was sued and required by the plaintiffs for their investment loss because of its financial statement. In this case, the company reached an agreement with the plaintiffs that it would give a one-time compensation (980 thousand RMB) to its plaintiffs and bear the court costs. As the company has purchased D&O insurance, its insurance issuers, American International Group, Inc., paid more than 80% of the compensation. Another claim case of D&O insurance occurred in the case of compensation for a calculation error of the ex-right reference price of Hareon Solar Technology Co., Ltd. (400074) in 2014, where the compensation was also partly paid by insurance issuers.

2.2. Hypothesis development

As one of the major corporate governance mechanisms, D&O insurance, introduced several decades ago in developed markets, has emerged as a focal point in corporate finance and risk management research. However, studies on the economic consequences of D&O insurance have not yet reached definitive and clear-cut conclusions. Some scholars have explored the adverse effects associated with D&O insurance, including higher financial costs (Chen et al., 2016), lower earnings quality (Chung et al., 2013), suboptimal M&A decisions (Lin et al., 2011), increased opportunistic behavior among executives (Chalmers et al., 2002), and higher firm default risk (Lin et al., 2013). Furthermore, Boubakri and Bouslimi (2016) present evidence suggesting that financial analysts exhibit less optimism in predicting the future earnings of firms with D&O insurance compared to those without. Chi and Weng (2014) document that Taiwanese-listed companies with excessive D&O liability insurance coverage are less inclined to engage high-quality auditors. Moreover, insured firms incur higher audit fees due to higher audit risk (Chung et al., 2015).

Another perspective takes a different view and argues that D&O insurance plays a positive influence on governance. For instance, Chung and Wynn (2008) find that firms with greater D&O insurance coverage tend to exhibit more aggressive earnings. Lin et al. (2019) document that when the management has a stake in the firm, D&O insurance leads to positive governance effects by curbing risk-taking activities related to financial reporting and corporate operating activities. Yuan et al. (2016) provide evidence that D&O insurance enhances corporate governance in Chinese-listed firms by decreasing firms' future stock price crash risk. Moreover, Chang et al. (2018) argue that only firms whose directors possess sufficient information can derive benefits from D&O insurance purchases.

Green innovation, which contributes to easing environmental burdens and advances sustainable development (Rennings, 2000), has attracted wide attention. Researchers also have put great effort into investigating the determinants of green innovation in terms of factors inside and outside the enterprises. From the view of internal factors, the literature examines the influence of corporate governance and strategy choice on firms' green innovation. Amore and Bennedsen (2016) show that corporate governance significantly influences firms' green innovation performance. Usman et al. (2020) document that board structure, such as board members' nationality differences and board independence, influences firms' green innovation. Liu and Kong (2021) provide evidence that prospector strategies negatively impact firms' green innovation compared with defender strategies.

Another branch of the literature examines the influence of external factors, including government tax, subsidy policy, and environmental regulation, on firms' green innovation. For instance, Frondel et al. (2007) and Borsatto and Amui (2019) show that firms' green innovation performance improves with the enhancement of environmental supervision. Stucki et al. (2018) find that taxes negatively influence firms' green innovation performance, while Huang et al. (2019) document that firms' green innovation performance improves with the effectiveness of government subsidies.

D&O insurance may exert two opposing effects on firms' green innovation. On one hand, serving as protection for directors and officers against claims alleging breach of their duties (Lin et al., 2011), D&O insurance assumes a pivotal supervisory role in corporate governance (Core, 2000; Holderness, 1990). Core (2000) contends that D&O insurers possess the ability to accurately evaluate the risks associated with insured firms and oversee management behavior through insurance pricing and contractual provisions.

In terms of firms' green innovation, the supervision effect of D&O insurance primarily manifests in the supervision role of D&O insurers regarding the managerial self-interest behavior of insured firms. Unlike routine investments, green innovation projects entail significant risk, cost, and long-term idiosyncratic investments characterized by uncertainty and failure risk (Holmstrom, 1989), which yield limited short-term economic benefits and often come with increased operating costs while reducing profits. The apprehension of profit decline and litigation risk stemming from shareholder claims of improper investment decisions dissuades risk-averse directors and officers from pursuing innovative endeavors. Managerial self-interest, due to the inherent agency conflict, diverts resources away from green innovation and seriously weakens the green innovation input and quality (Islam & Rahman, 2023; Wright et al., 1996). To mitigate potential future losses from litigations, D&O insurers are incentivized to closely monitor managerial self-interest behavior (Baker & Griffith, 2007). This external monitoring by D&O insurers serves to curb management opportunism, foster diligence and accountability among managers, optimize resource allocation for green innovation, prevent the oversight of high-quality green innovation projects, and consequently enhance firms' green innovation initiatives.

On the other hand, litigation risk protection provided by D&O insurance constructs an isolation mechanism between managers' personal wealth and behavior consequences, significantly reducing the disciplinary effect of legal proceedings on the management (Chen et al., 2016). Therefore, managers are expected to reduce diligence and prudence when performing their duties, which reduces decision-making quality and encourages moral hazard and opportunistic behavior (Chalmers et al., 2002). In this instance, insured firms' managers may consume private benefits or squander corporate resources, negatively influencing investments in firms' green innovation projects. Therefore, whether firms with D&O insurance purchases are more likely to pursue better green innovation performance is an open empirical question. Our discussion yields our hypothesis (stated in the null form):

H1. *Ceteris paribus*, the D&O legal liability coverage does not affect firm green innovation.

3. Sample selection and research design

3.1. Sample and data

Our initial sample is all publicly listed Chinese firms on the Shanghai and Shenzhen stock exchanges over 2002–2019 (n = 40,441). The sample period starts in 2002 because the first D&O insurance in China's stock market appeared that year. We deleted financial firms (765 observations) due to the comparability of their accounting statements and firms with missing financial data needed for the

empirical tests (6038 observations). Our final sample consists of 3471 firms, making 33,638 firm-year observations.

Following Yuan et al. (2016), we manually collect the data on D&O insurance from firms' annual reports and disclosed minutes of boards' and shareholders' meetings, as China's Securities and Regulatory Commission (CSRC) requires that any purchase of D&O insurance to be proposed by the board of directors and approved at shareholders' annual meeting. The data on green innovation patents and citations of green innovation is from the Green Patent Research Database, a professional database developed by combining Chinese patent data and the green patent classification number standard published by the World Intellectual Property Office, provided by the Chinese Research Data Services Platform (CNRDS). The data for all financial variables is from the China Stock Market Accounting Research (CSMAR) database. To alleviate the undue influence of outliers, we winterize all continuous variables at the top and bottom 1% percentiles.

3.2. Measures of firms' green innovation

Following prior literature (e.g., Liu & Kong, 2021; Quan et al., 2021; Wang et al., 2022), we use green patents to capture a firm's green innovation (*GI*) performance. We use variables *PatentI*, *PatentU*, and *PatentT* to measure *GI*, where *PatentI* (*PatentU*) is computed as the natural logarithm of one plus the number of granted green invention patents (green utility model patents), and *PatentT* is equal to the natural logarithm of one plus the total number of granted green invention patents and green utility model patents. Therefore, higher values of *PatentI*, *PatentU*, and *PatentT* indicate better firm green innovation.

3.3. Empirical model

We use the following regression model to test the relationship between D&O insurance (*DOI*) and firms' green innovation (*GI*):

$$Ln\left(1+GI_{i,t+1}\right)=\beta_0+\beta_1 DOI_{i,t}+Controls+Fixed\ \ Effects+\varepsilon_{i,t} \tag{1}$$

In Eq. (1), *GI* is firms' green innovation measured by *PatentI*, *PatentU*, and *PatentT* for year $t+1$, while all explanatory variables are measured in year *t*. *DOI* is a dummy variable equal to 1 if the company purchases D&O insurance in the fiscal year, and 0 otherwise.[2] We focus on the effect of D&O insurance (*DOI*) on green innovation (*GI*), that is β_1, the coefficient on variable *DOI*. Following prior research (e.g., Brav et al., 2018; Guo et al., 2019; Liu & Kong, 2021; Quan et al., 2021; Usman et al., 2020; Wang et al., 2022), we control for firm size (*Size*), leverage (*Leverage*), age (*Age*), profitability (*Profitability*), tangibility (*Tangibility*), Tobin's Q (*Tobin's Q*), industry competition (*Herfindahl* and squared *Herfindahl* based of sales income) and institutional ownership (*InstOwn*). Finally, we control for the year- and industry-fixed effects. The variable definitions can be seen in the Appendix.

4. Empirical results

4.1. Descriptive statistics

Table 1 presents the basic descriptive statistics of the variables used in our empirical analysis. In Panel A, the mean of *DOI* reveals that only about 5% of the observations have purchased a D&O insurance, which is significantly different from the developed western markets (e.g., the U.S. and Canada). The means (75th percentile) of variables *PantentI* and *PatentU* are 0.094 (0.000) and 0.164 (0.000), respectively, suggesting that the majority of the Chinese-listed firms do not have any green patents and citations. Overall, these findings are similar to prior literature research (e.g., Liu & Kong, 2021; Quan et al., 2021; Wang et al., 2022) and indicate that Chinese firms' green innovation is burgeoning.

Panel B shows that sample firms are relatively dispersed among industries.[3] More importantly, we observe that firms in industries exposed to a higher risk of lawsuits and regulation sanctions, such as the printing industry, mining industry, and paper and allied products industry, are more likely to purchase D&O insurance. However, no firm in the furniture manufacturing industry buys D&O insurance, and the reason may be that furniture manufacturing firms suffer from a low risk of lawsuits and regulation sanctions. Panel C shows the descriptive statistics for the two subsamples when the sample is partitioned depending on whether firms are insured (*DOI* = 1) or not (*DOI* = 0), and presents the values of the t-tests and Wilcoxon z-tests for differences in means and medians between the two types of firms. We find that firms with D&O insurance exhibit more green invention patents and green utility model patents than uninsured firms, which lends preliminary support to the contention that firms with D&O insurance significantly enhance green innovation performance.

4.2. Correlation analysis

In Table 2, the lower (upper) triangle shows Pearson (Spearman rank) correlation coefficients. The results reveal that the D&O

[2] Most of the Chinese listed firms purchasing D&O insurance do not disclose the insurance fees, therefore following Yuan et al. (2016) and Zou et al. (2008), we employ a dummy variable to measure the behavior of firms purchasing D&O insurance.

[3] Our industry classification is based on the CSRC industry classification scheme. Following prior studies (e.g., Guan et al., 2016; Gul et al., 2013), we use two-digit codes for the manufacturing sector and one-digit codes for the other sectors.

Table 1
Descriptive statistics.

Panel A: Descriptive statistics for the full sample

Variables	N	Mean	Standard deviation	First quartile	Median	Third quartile
$PatentI_{t+1}$	33,638	0.094	0.342	0.000	0.000	0.000
$PatentU_{t+1}$	33,638	0.164	0.490	0.000	0.000	0.000
$PatentT_{t+1}$	33,638	0.222	0.583	0.000	0.000	0.000
DOI	33,638	0.051	0.219	0.000	0.000	0.000
Size	33,638	21.114	1.488	20.131	21.014	21.983
Leverage	33,638	0.451	0.217	0.282	0.447	0.608
Age	33,638	2.155	0.712	1.609	2.303	2.773
Profitability	33,638	0.077	0.068	0.049	0.076	0.110
Tangibility	33,638	0.242	0.177	0.104	0.207	0.345
Tobin's Q	33,638	1.969	1.315	1.203	1.528	2.193
Herfindahl	33,638	0.060	0.092	0.015	0.018	0.066
InstOwn	33,638	0.308	0.247	0.070	0.281	0.505
ROA	33,638	0.034	0.066	0.013	0.035	0.064
Foreign	33,638	0.015	0.121	0.000	0.000	0.000
SOE	33,638	0.438	0.496	0.000	0.000	1.000
BoardIndep	33,638	0.363	0.060	0.333	0.333	0.400
ManHold	32,548	0.078	0.161	0.000	0.000	0.037
Violation	33,638	0.180	0.384	0.000	0.000	0.000
Balance	32,548	0.668	0.592	0.198	0.503	0.972
BM	33,638	0.639	0.240	0.456	0.655	0.831
MeanIndDOI	33,638	0.051	0.032	0.040	0.040	0.052
Growth	31,604	0.215	0.541	−0.015	0.125	0.302
Board	33,491	2.275	0.184	2.197	2.303	2.303

Panel B: Distribution by industry

Industry	N	%(Total)	$DOI = 1$	%($DOI = 1$)
Farming, Forestry, Animal Husbandry, and Fishing	599	1.78	28	4.67
Mining	775	2.30	92	11.87
Food and Beverage	1370	4.07	49	3.58
Textile, Apparel, Fur, and Leather	1092	3.25	29	2.66
Furniture Manufacturing	191	0.57	0	0.00
Paper and Allied Products; Printing	492	1.46	41	8.33
Petroleum, Chemical, Plastics, and Rubber Products	3592	10.68	124	3.45
Electronics	2823	8.39	102	3.61
Metal and Non-metal	2763	8.21	153	5.54
Machinery, Equipment, and Instrument Manufacturing	6575	19.55	226	3.44
Medicine and Biological Products	2099	6.24	109	5.19
Other Manufacturing	437	1.30	7	1.60
Utilities	1223	3.64	81	6.62
Construction	843	2.51	32	3.80
Transportation and Warehousing	1132	3.37	208	18.37
Information Technology	1771	5.26	38	2.15
Wholesale and Retail Trades	2010	5.98	150	7.46
Real Estate	1608	4.78	127	7.90
Public Facilities and Other Services	1188	3.53	60	5.05
Communication and Cultural Industries	329	0.98	21	6.38
Conglomerates	726	2.16	24	3.31
Total	33,638	100	1701	5.06

Panel C: Descriptive statistics for separate subsamples divided by dummy variable *DOI*

Variables	$DOI = 1$			$DOI = 0$			Differences	
	N	Mean	Median	N	Mean	Median	t-value	z-value
$PatentI_{t+1}$	1701	**0.180**	0.000	31,937	**0.089**	0.000	**10.732*****	8.212***
$PatentU_{t+1}$	1701	**0.266**	0.000	31,937	**0.158**	0.000	**8.8412*****	5.166***
$PatentT_{t+1}$	1701	**0.350**	0.000	31,937	**0.215**	0.000	**9.312*****	5.110***
Size	1701	22.271	22.139	31,937	21.052	20.972	33.458***	27.728***
Leverage	1701	0.546	0.566	31,937	0.445	0.440	18.733***	19.265***
Age	1701	2.595	2.708	31,937	2.131	2.197	26.444***	27.320***
Profitability	1701	0.075	0.074	31,937	0.077	0.076	−1.009	−1.629
Tangibility	1701	0.268	0.229	31,937	0.240	0.205	6.233***	4.567***
Tobin's Q	1701	1.713	1.318	31,937	1.982	1.540	−8.215***	−15.291***
Herfindahl	1701	0.067	0.029	31,937	0.060	0.017	3.192***	6.858***
InstOwn	1701	0.438	0.449	31,937	0.301	0.271	22.385***	20.408***

Notes: This table presents descriptive statistics. Panel A presents descriptive statistics for the variables used in our D&O insurance and firms' green innovation analysis. Panel B presents the sample distribution by industry. Panel C presents the results of univariate analysis on the mean and median

differences of the dependent variables and control variables between the group of firms that do not have insurance (*DOI* = 0) and the group of firms that have insurance (*DOI* = 1). The t-values and z-values for differences in means (medians) are based on t-tests (Wilcoxon tests). *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. All continuous variables have been winsorized at the 1st and 99th percentiles. Variables are defined in the Appendix.

insurance variable (*DOI*) is positively and significantly associated with the three measures for green innovation (*PatentI*, *PatentU*, and *PatentT*), indicating that firms with D&O insurance achieve better green innovation performance, again preliminary supporting that D&O insurance motivates directors and officers to actively pursue better green innovation performance. To further test the existence of multicollinearity, we compute the variance inflation factor (VIF) for independent variables. The maximum (average) value is 2.63 (1.63), well below the rule of thumb cutoff of 10 for multiple regression models. In addition, the correlations between control variables are generally small, suggesting that multicollinearity is unlikely to be a serious problem in our study.

4.3. Main results

Table 3 presents the regression results for hypothesis H1. In columns (1), (3), and (5), we show that the coefficients on *DOI* are significantly positive at the 1% level, respectively, when we control only for year- and industry-fixed effects. When we add the full set of control variables to the regression in columns (2), (4), and (6), the coefficients on variable *DOI* remain positive and statistically significant below the 1% threshold level ($p < 0.01$). Overall, these results again support the hypothesis that compared with uninsured firms, firms purchasing D&O insurance achieve better green innovation performance. Economically, ceteris paribus, listed firms are able to achieve green invention patents ($PatentI_{t+1}$) about 4.7% ($=e^{0.046}$-1) higher after they purchase D&O insurance. Similarly, ceteris paribus, listed firms are able to achieve green utility model patents ($PatentU_{t+1}$), and the total of green invention patents and green utility model patents ($PatentT_{t+1}$) about 5% ($=e^{0.049}$-1) and 6.2% ($=e^{0.060}$-1) higher after they purchase D&O insurance, respectively.

The coefficients of the control variables are generally consistent with prior studies (e.g., Guo et al., 2019; Liu & Kong, 2021; Quan et al., 2021). Specifically, firms with bigger sizes, younger ages, less fixed assets, and better corporate governance are associated with better green innovation performance.

5. Robustness checks

5.1. Propensity score matching and entropy balancing approaches

Although we document that D&O insurance advances firms' green innovation, it is important to stress that our evidence on green innovation may be driven by certain differences between insured firms (treatment firms) and uninsured firms (control firms). To alleviate this threat to reliable identification, we implement propensity score matching (PSM) and entropy balancing approaches to align the attributes between treatment and control firms.

To apply the PSM approach, we first estimate the propensity score for treatment firms employing a logit model based on the full sample. The covariates in the first stage are the control variables used in our baseline model (Shipmen et al., 2017). Column (1) in Table 4 (Panel A) portrays the results. For each treatment firm, we identify a firm without D&O insurance with the closest propensity score estimated as its control match. Specifically, we use a one-to-one matching procedure without replacement and set the caliper distance at 0.01. We identify 1688 pairs of firms and drop the unmatched firms from the analysis.

To check the covariate balance between the insured and the matched uninsured firms, we re-estimate the logit model using the matched pairs. As shown in Column (2), none of the covariates loads with a significant coefficient, indicating that the treatment and control groups are closely aligned in the relevant covariates. In addition, Fig. 1(a) and (b) show the kernel density functions of the *Treatment group* and the *Control group*, based on pre- and post-matching of the two groups, respectively. The kernel density functions of the two groups are significantly different before matching. In contrast, we choose firms from the *Control group* to match those in the *Treatment group* based on propensity scores. After matching, as shown in Fig. 1(b), the kernel density functions of the two groups are much closer, indicating that the characteristics of the variables in the two groups are similar after matching.

Finally, we re-estimate our baseline model using the matched samples. Panel B reports the results and shows that the coefficients on *DOI* continue to be positive and statistically significant at below the 1% threshold level. Hence, our results are robust after controlling for potential differences mentioned in previous research between insured and uninsured firms.

In addition, we implement the entropy balancing approach. Specifically, following Hainmueller (2012), we use the entropy balancing approach to balance the first three moments (i.e., mean, variance, and skewness) of the control variables across the treatment (insured) and control (uninsured) firms. Panel A of Table 5 shows the matching efficiency of the entropy balancing method, illustrating a decrease in the differences for these control variables between the treatment group and the control group after matching. Panel B of Table 5 reports the results from estimating our main analysis based on the reweighted variables. We find that the coefficients on *DOI* remain positive and statistically significant at below the 1% threshold level. Thus, our main results remain qualitatively the same and hold after balancing pre-treatment confounders across the treated and control groups.

5.2. Heckman's two-stage regression results

A firm's decision to purchase D&O insurance may be non-random, leading to a self-selection bias. For instance, firms with more

Table 2
Correlation matrix.

		1	2	3	4	5	6	7	8	9	10	11	12
1	$PatentI_{t+1}$		0.420***	0.707***	**0.045***	0.165***	0.020***	−0.008	0.010*	−0.029***	−0.004	−0.066***	0.128***
2	$PatentU_{t+1}$	0.527***		0.876***	**0.028***	0.172***	0.022***	−0.048***	0.012**	−0.026***	−0.033***	−0.093***	0.113***
3	$PatentT_{t+1}$	0.780***	0.918***		**0.028***	0.184***	0.006	−0.050***	0.017***	−0.028***	−0.012**	−0.110***	0.130***
4	***DOI***	**0.058***	**0.048***	**0.051***		0.151***	0.105***	0.149***	−0.009	0.025***	−0.083***	0.037***	0.111***
5	*Size*	0.218***	0.230***	0.247***	0.179***		0.362***	0.294***	0.180***	0.070***	−0.348***	−0.029***	0.448***
6	*Leverage*	0.025***	0.037***	0.027***	0.102***	0.308***		0.365***	−0.275***	0.085***	−0.308***	0.108***	0.080***
7	*Age*	0.010*	−0.027***	−0.024***	0.143***	0.258***	0.379***		−0.166***	0.026***	−0.003	0.068***	0.338***
8	*Profitability*	0.019***	0.025***	0.027***	−0.006	0.213***	−0.302***	−0.143***		0.210***	0.155***	−0.061***	0.139***
9	*Tangibility*	−0.026***	−0.030***	−0.034***	0.034***	0.083***	0.119***	0.079***	0.123***		−0.142***	−0.133***	−0.036***
10	*Tobin's Q*	−0.030***	−0.061***	−0.053***	−0.045***	−0.332***	−0.155***	0.096***	0.041***	−0.121***		−0.066***	0.166***
11	*Herfindahl*	0.009*	−0.012**	−0.009*	0.017***	−0.038***	−0.035***	−0.040***	0.026***	−0.071***	0.052***		0.015***
12	*InstOwn*	0.140***	0.132***	0.150***	0.121***	0.451***	0.084***	0.330***	0.159***	−0.007	0.136***	0.034***	

Notes: This table shows Pearson and Spearmen correlation coefficients for the variables used in the main regression analysis. Pearson (Spearman rank) correlations are in the lower-left (upper-right) corner of the correlation matrix. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. All continuous variables have been winsorized at the 1st and 99th percentiles. Variables are defined in the Appendix.

Table 3
D&O insurance and firms' green innovation.

Variables	$Y = PatentI_{t+1}$		$Y = PatentU_{t+1}$		$Y = PatentT_{t+1}$	
	(1)	(2)	(3)	(4)	(5)	(6)
DOI	**0.098*** **	**0.046*** **	**0.117*** **	**0.049*** **	**0.150*** **	**0.060*** **
	(8.211)	**(4.061)**	**(7.522)**	**(3.294)**	**(8.163)**	**(3.461)**
Size		0.051***		0.072***		0.094***
		(23.564)		(24.616)		(27.580)
Leverage		−0.012		0.034***		0.008
		(–1.306)		(2.654)		(0.541)
Age		−0.019***		−0.052***		−0.059***
		(–6.383)		(–12.136)		(–11.891)
Profitability		−0.211***		−0.200***		−0.315***
		(–8.100)		(–5.602)		(–7.358)
Tangible		−0.041***		−0.033**		−0.050**
		(–3.403)		(–2.023)		(–2.575)
Tobin's Q		0.004***		0.001		0.002
		(2.739)		(0.686)		(1.050)
Herfindahl		0.147**		0.403***		0.374***
		(2.127)		(5.091)		(3.517)
$Herfindahl^2$		−0.046		−0.275***		−0.193*
		(–0.616)		(–3.721)		(–1.673)
InstOwn		0.076***		0.090***		0.132***
		(7.613)		(6.428)		(7.975)
Year-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Intercept	−0.092***	−1.084***	−0.164***	−1.561***	−0.219***	−2.024***
	(–14.594)	(–22.099)	(–18.694)	(–23.106)	(–19.703)	(–25.688)
Observations	33,638	33,638	33,638	33,638	33,638	33,638
Adj. R^2	0.051	0.093	0.091	0.135	0.098	0.150

Notes: The table presents the results of the OLS regressions. The *t*-statistics are in parentheses below the regression coefficients and are calculated using Huber-White's (1980) heteroskedastic-consistent standard errors. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively, based on two-tailed tests. All continuous variables are winsorized at the 1st and 99th percentiles. Variables are defined in the Appendix.

green innovation activities may be more at risk and more likely to purchase D&O insurance. We employ the Heckman (1979) two-stage approach to mitigate this potential endogeneity concern as a robustness check. In the first step, we estimate a probit model with a dummy variable *DOI* for D&O insurance purchases as the dependent variable using the total sample. Following prior research (Chung & Wynn, 2008; Yuan et al., 2016), we add the following determinants of D&O insurance purchases: firm size (*Size*), leverage (*Leverage*), return on assets (*ROA*), whether the firm has issued H-shares or B-shares (*Foreign*), the nature of the firm (i.e., state-owned enterprise or not, *SOE*), the proportion of independent directors (*BoardIndep*), equity ownership of the management (*ManHold*), whether a given firm has a violation record (*Violation*), controlling shareholder's power, measured by the sum of shareholdings of the second to fifth largest shareholders divided by the shareholdings of the largest shareholder (*Balance*), book-to-market ratio (*BM*), and the mean incidence of D&O insurance purchases for firms in the same industry in the same year, excluding the firm concerned (*MeanIndDOI*).

Firms in the same industry are expected to compete for the same pool of managerial talent. To compete effectively, compensation packages —including D&O insurance coverage— need to be comparable to those offered by industry competitors (Adams et al., 2011; Chung et al., 2015). In addition, firms in the same industry face similar business conditions, including litigation risk. Therefore, we use *MeanIndDOI* as an exogenous IV because industry D&O insurance means coverage will be correlated with a firm's D&O insurance coverage but is unlikely to directly influence the firm's green innovation except through the firm's D&O coverage. The specification of the probit model is as follows

$$\begin{aligned} DOI_{i,t} = {} & \beta 0 + \beta 1 \times Size_{i,t} + \beta 2 \times Lev_{i,t} + \beta 3 \times Roa_{i,t} + \beta 4 \times Foreign_{i,t} + \beta 5 \times SOE_{i,t} \\ & + \beta 6 \times BoardIndep_{i,t} + \beta 7 \times ManHold_{i,t} + \beta 8 \times Violation_{i,t} \\ & + \beta 9 \times Balance_{i,t} + \beta 10 \times BM_{i,t} + Year\ \ Fixed\ \ Effects \\ & + Industry\ \ Fixed\ \ Effects + \varepsilon_{i,t} \end{aligned} \tag{2}$$

The inverse Mills ratio (*IMR*) is generated and then included in the second-step model to control potential sample selection bias. The specification of the second-step model is the same as the models described in Section 3.3. Table 6 reports the regression results of the Heckman model. The results of the first-step regression in Panel A show that *Size*, *Leverage*, *Foreign*, *SOE*, *BoardIndep*, and *Balance* have positive and statistically significant impacts on a firm's decision to purchase D&O insurance. In contrast, *ManHold* has a negative and statistically significant impact, consistent with prior research (e.g., Yuan et al., 2016). In Panel B, the coefficients on *DOI* continue to be positive and statistically significant ($p < 0.01$) after we control for the variable *IMR*, which indicates that our results are robust after controlling for potential sample selection bias.

Table 4
Robust-check results using the PSM method.

Variables	Panel A: First stage		Panel B: Second stage		
	(1) Logit regression	(2) Balance test	(3)	(4)	(5)
	y = DOI		y = $PatentI_{t+1}$	y = $PatentU_{t+1}$	y = $PatentT_{t+1}$
DOI			**0.047*** **	**0.066*** **	**0.077*** **
			(3.332)	**(3.564)**	**(3.521)**
Size	0.433***	0.018	0.082***	0.110***	0.140***
	(17.141)	(0.581)	(11.488)	(12.058)	(13.038)
Leverage	0.433**	0.017	−0.131***	−0.147***	−0.208***
	(2.494)	(0.077)	(–3.251)	(–2.890)	(–3.378)
Age	0.921***	−0.064	−0.010	0.020	0.009
	(15.620)	(–0.820)	(–0.624)	(0.960)	(0.370)
Profitability	−2.001***	−0.328	−0.298**	−0.174	−0.316*
	(–4.370)	(–0.532)	(–2.520)	(–1.178)	(–1.761)
Tangible	−0.127	0.218	0.164***	0.156***	0.231***
	(–0.715)	(0.996)	(3.540)	(2.641)	(3.318)
Tobin's Q	0.059**	0.002	−0.003	−0.003	−0.008
	(2.132)	(0.043)	(–0.532)	(–0.410)	(–1.043)
Herfindahl	2.545**	−0.554	0.434	0.405	0.519
	(2.036)	(–0.388)	(1.638)	(1.426)	(1.279)
$Herfindahl^2$	−1.092	−0.674	−0.314	−0.768***	−0.672
	(–1.005)	(–0.523)	(–0.935)	(–3.107)	(–1.363)
InstOwn	0.411***	0.072	0.103***	0.042	0.071
	(2.899)	(0.388)	(2.687)	(0.801)	(1.173)
Year-fixed effects	Yes	Yes	Yes	Yes	Yes
Industry-fixed effects	Yes	Yes	Yes	Yes	Yes
Intercept	−15.430***	−0.418	−1.752***	−2.380***	−2.995***
	(–26.889)	(–0.570)	(–10.249)	(–10.216)	(–10.923)
Observations	33,638	3376	3376	3376	3376
Adj./Pseudo R^2	0.138	0.004	0.203	0.241	0.270

Notes: The table presents the results of the Logit (OLS) regressions in Panel A(B). The z/*t*-statistics are in parentheses below the regression coefficients and are calculated using Huber-White's (1980) heteroskedastic-consistent standard errors in the first (second) stage regressions. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively, based on two-tailed tests. All continuous variables are winsorized at the 1st and 99th percentiles. Variables are defined in the Appendix.

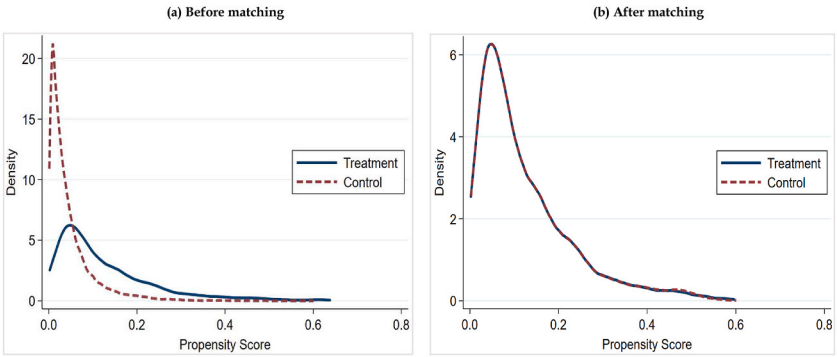

Fig. 1. Kernel density of propensity score before and after PSM
Notes: The figure presents the distributions of propensity scores before and after the propensity score match (PSM). Specifically, Fig. 1(a) presents the propensity scores before matching, whereas Fig. 1(b) presents the propensity scores after matching.

5.3. Fixed effects model

Although a fixed-effects (change analysis) estimating would alleviate the threat posed by correlated omitted variables, including time-invariant selectivity, data inspection reveals that *DOI* status is highly stable during the sample period, with only 0.69 percent (0.03 percent) of the observations changing from *DOI* = 0 to *DOI* = 1 (*DOI* = 1 to *DOI* = 0). Importantly, the poor within variation of the variable *DOI* would leave a fixed-effects (change analysis) estimating prone to failing to detect a significant relationship between *DOI* and green innovation (e.g., El Ghoul et al., 2016; Zhou, 2001). Therefore, because *DOI* status suffers from minimal time-series variation in our setting, a fixed-effects (change analysis) estimating would yield inefficient estimates on the *DOI* test variable (Beck, 2001; Plümper & Troeger, 2007).

However, to ensure that our baseline regression results do not suffer from omitted variables that may not vary with time, we

Table 5
Robust-check results using the Entropy Balancing method.

Panel A: Matching efficiency of the entropy balancing method

Variables	Treatment			Control before matching			Control after matching		
	Mean	Variance	Skewness	Mean	Variance	Skewness	Mean	Variance	Skewness
Size	22.271	3.150	−0.025	21.052	2.089	0.242	22.270	3.150	−0.023
Leverage	0.546	0.042	−0.200	0.445	0.047	0.268	0.546	0.042	−0.200
Age	2.595	0.265	−1.198	2.132	0.509	−0.473	2.595	0.265	−1.197
Profitability	0.075	0.005	−0.926	0.077	0.005	−1.129	0.075	0.005	−0.926
Tangibility	0.268	0.039	0.572	0.240	0.031	0.884	0.268	0.039	0.572
Tobin's Q	1.714	1.428	3.524	1.982	1.741	2.939	1.714	1.428	3.524
Herfindahl	0.067	0.008	2.455	0.060	0.008	2.799	0.067	0.008	2.455
Herfindahl^2	0.014	0.002	8.892	0.014	0.003	8.798	0.014	0.002	8.892
InstOwn	0.438	0.069	−0.118	0.301	0.060	0.411	0.438	0.069	−0.118

Panel B: Results about the impact of D&O insurance on firms' green innovation, using the entropy-balanced samples

Variables	(1)	(2)	(3)
	$y = PatentI_{t+1}$	$y = PatentU_{t+1}$	$y = PatentT_{t+1}$
DOI	**0.045*****	**0.050*****	**0.062*****
	(3.980)	**(3.411)**	**(3.610)**
Size	0.077***	0.105***	0.132***
	(13.773)	(14.494)	(15.688)
Leverage	−0.108***	−0.111***	−0.158***
	(–3.419)	(–2.844)	(–3.348)
Age	−0.018	−0.008	−0.023
	(–1.341)	(–0.468)	(–1.118)
Profitability	−0.204**	−0.076	−0.188
	(–2.368)	(–0.701)	(–1.447)
Tangible	0.094**	0.093**	0.134**
	(2.503)	(2.015)	(2.455)
Tobin's Q	−0.003	−0.004	−0.009
	(–0.827)	(–0.921)	(–1.586)
Herfindahl	0.434***	0.553***	0.681***
	(2.805)	(3.176)	(2.861)
Herfindahl^2	−0.349*	−0.830***	−0.743**
	(–1.765)	(–4.878)	(–2.563)
InstOwn	0.124***	0.083**	0.127***
	(4.117)	(1.993)	(2.657)
Year-fixed effects	Yes	Yes	Yes
Industry-fixed effects	Yes	Yes	Yes
Intercept	−1.612***	−2.143***	−2.766***
	(–12.206)	(–12.110)	(–13.519)
Observations	33,638	33,638	33,638
Adj. R^2	0.206	0.245	0.275

Notes: This table presents the results using the Entropy Balancing method. Panel A shows the matching efficiency of the entropy balancing method. Panel B shows the result of the impact of D&O insurance on firms' green innovation using the entropy-balanced samples. Numbers reported are regression coefficients with *t*-statistics in parentheses in Panel B. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively, based on two-tailed tests. All continuous variables are winsorized at the 1st and 99th percentiles. Variables are defined in the Appendix.

continue to add the firm fixed effects into our baseline model in Section 3.3. Table 7 reports the results and shows that although a fixed-effects estimate in our setting is prone to failing to detect a significant coefficient estimating, we still show that the coefficients on *DOI* are all positive and significant ($p < 0.01$). Therefore, our findings are not likely to suffer from potential omitted variables.

5.4. Alternative measures for green innovation

In the above analyses, we forward green innovation by one period to account for the possible delaying effect of D&O insurance when measuring firm green innovation performance (*GI*). However, the time could be too short to capture the total effects, as the grant of green invention patents and green utility patents takes time. To investigate this possibility, we further measure *PatentI*, *PatentU*, and *PatentT* at both year t+2 and year t+3. The results of using these two measures of green innovation are in Table 8. The coefficients on *DOI* remain positive across all model specifications at the 1% threshold level. Therefore, our findings are robust when we use alternative measures for green innovation that consider lag in green innovation.

Table 6
Heckman-two stage results.

Panel A: First stage		Panel B: Second stage			
Variables	(1)	Variables	(2)	(3)	(4)
	$y = DOI$		$y = PatentI_{t+1}$	$y = PatentU_{t+1}$	$y = PatentT_{t+1}$
MeanIndDOI	12.630***	***DOI***	0.043***	0.046***	0.056***
	(4.885)		(3.734)	(3.074)	(3.189)
Size	0.155***	***IMR***	−0.043***	−0.028**	−0.046***
	(14.100)		(–5.407)	(–2.470)	(–3.461)
Leverage	0.487***	*Size*	0.046***	0.070***	0.089***
	(6.947)		(18.870)	(21.270)	(22.992)
ROA	0.000	*Leverage*	−0.033***	0.022	−0.013
	(0.088)		(–3.182)	(1.552)	(–0.742)
Foreign	0.635***	*Age*	−0.026***	−0.057***	−0.067***
	(9.389)		(–7.686)	(–11.641)	(–11.854)
SOE	0.270***	*Profitability*	−0.198***	−0.184***	−0.295***
	(8.761)		(–7.359)	(–4.976)	(–6.650)
BoardIndep	0.982***	*Tangible*	−0.054***	−0.044**	−0.068***
	(4.529)		(–4.246)	(–2.550)	(–3.270)
Manhold	−1.838***	*Tobin's Q*	0.003**	0.001	0.001
	(–9.460)		(1.995)	(0.285)	(0.472)
Violation	−0.024	*Herfindahl*	0.166**	0.400***	0.381***
	(–0.697)		(2.231)	(4.697)	(3.324)
Balance	0.139***	$Herfindahl^2$	−0.061	−0.288***	−0.215
	(6.109)		(–0.709)	(–3.281)	(–1.623)
BM	−0.110	*InstOwn*	0.062***	0.082***	0.118***
	(–1.530)		(5.939)	(5.489)	(6.789)
Intercept	−6.025***	Intercept	−0.649***	−0.944***	−1.213***
	(–22.859)		(–9.374)	(–9.415)	(–10.365)
Year-fixed effects	Yes	Year-fixed effects	Yes	Yes	Yes
Industry-fixed effects	Yes	Industry-fixed effects	Yes	Yes	Yes
N	32,339	N	32,339	32,339	32,339
Pseudo R^2	0.140	Adj. R^2	0.094	0.136	0.150

Notes: The table presents the results of the Probit (OLS) regressions in Panel A(B). The z/*t*-statistics are in parentheses below the regression coefficients and are calculated using Huber-White's (1980) heteroskedastic-consistent standard errors in the first (second) stage regressions. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively, based on two-tailed tests. All continuous variables are winsorized at the 1st and 99th percentiles. Variables are defined in the Appendix.

6. Additional tests

6.1. Heterogeneity analysis

In this section, we perform cross-sectional tests to shed light on the heterogeneities in the effect of D&O insurance on green innovation output. We can further support our hypothesis by observing expected cross-sectional patterns based on the hypothesized mechanisms through which D&O insurance affects innovation (Rajan & Zingales, 1988; Aghion et al., 2013). We partition our sample firms into low- and high-subsamples depending on firms' litigation risk, political connection (*PC*), and corporate governance quality. We separately estimate Eq. (1) on these two subsamples and report the results in Table 9–11.

6.1.1. The role of the litigation risk

As mentioned in Section 2.2, the fear of litigation risk discourages directors and officers from actively engaging in green innovation activities that are inherently risky. We argue that the function of loss compensation provided by D&O insurance to managers alleviates their risk aversion tendency and thus encourages them to actively invest more in green innovation projects. To the extent that this argument holds, we expect the increase in green innovation output to be more pronounced for firms exposed to higher litigation risk. We employ the legal environment index from Wang et al. (2019) to measure firms' litigation risk because firms and their directors and officers are more likely to suffer from lawsuits when firms located in provinces with a higher degree of legalization and sound legal intermediary organizations, which the legal environment index captures. We use litigation risk as a partitioning variable to test our conjecture. Based on the company's location, we divide the sample into a *High* litigation risk group (firms located in provinces with a legal environment index equal to or above the sample median) and a *Low* litigation risk group (firms located in provinces with a legal environment index below the sample median). We then rerun our main analysis on both subsamples (See Table 9) and show that the coefficients on *DOI* are all positive and statistically significant in the high-litigation-risk subsample and the low-litigation-risk subsample except in Column (2). More importantly, the coefficients on *DOI* are all statistically larger in the high-litigation-risk subsample, as evidenced by the *p*-values of the tests of differences in coefficients reported at the bottom of Table 9. These results support the rationale that the effect of D&O insurance on green innovation is more pronounced for firms exposed to a higher risk of litigation.

Table 7
Robust-check results using fixed effects model.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	$y = PatentI_{t+1}$	$y = PatentI_{t+1}$	$y = PatentU_{t+1}$	$y = PatentU_{t+1}$	$y = PatentT_{t+1}$	$y = PatentT_{t+1}$
DOI	0.048***	0.048***	0.055***	0.057***	0.051***	0.052***
	(3.921)	(3.902)	(3.363)	(3.453)	(2.764)	(2.830)
Size		0.013***		0.023***		0.030***
		(5.151)		(6.417)		(7.666)
Leverage		0.025**		0.019		0.021
		(2.022)		(1.149)		(1.109)
Age		0.042***		0.053***		0.081***
		(5.879)		(5.463)		(7.544)
Profitability		−0.113***		−0.089**		−0.183***
		(–4.076)		(–2.396)		(–4.420)
Tangible		0.052***		0.093***		0.117***
		(3.466)		(4.567)		(5.149)
Tobin's Q		−0.007***		−0.007***		−0.010***
		(–4.089)		(–3.049)		(–4.166)
Herfindahl		−0.114***		0.157***		−0.036
		(–2.845)		(2.896)		(–0.605)
$Herfindahl^2$		−0.034		−0.319***		−0.216***
		(–0.703)		(–4.938)		(–3.005)
InstOwn		−0.010		−0.009		−0.011
		(–1.041)		(–0.668)		(–0.784)
Year-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Firm-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Intercept	0.091***	−0.274***	0.160***	−0.442***	0.218***	−0.584***
	(61.666)	(–5.082)	(80.422)	(–6.081)	(98.176)	(–7.206)
Observations	33,638	33,638	33,638	33,638	33,638	33,638
Adj. R^2	0.482	0.485	0.540	0.543	0.597	0.601

Notes: The table presents the results of the OLS regressions. The *t*-statistics are in parentheses below the regression coefficients and are calculated using Huber-White's (1980) heteroskedastic-consistent standard errors. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively, based on two-tailed tests. All continuous variables are winsorized at the 1st and 99th percentiles. Variables are defined in the Appendix.

6.1.2. The role of political connection

On the one hand, prior studies provide evidence that politically connected Chinese-listed firms (PCs) can obtain favorable treatment and support from the government (e.g., Lin et al., 2015; Wang et al., 2008). On the other hand, firms with political connections tend to pursue corporate social responsibility to cater to the government (e.g., Wang & Qian, 2011). In this scene, the compensation function of D&O insurance may be weaker because the political connection can protect these firms and their managers from litigation risk (Jia et al., 2019). Moreover, firms with political connections have more motivation to engage in activities (such as green innovation projects) to improve their environmental performance and practice their corporate social responsibility. Therefore, we argue that compared with firms without PCs, the effect of D&O insurance is weaker for firms with PCs.

To test the above conjecture, we divide the total sample into PCs and Non-PCs groups. Specifically, following prior literature (e.g., Fan et al., 2007; Wang et al., 2008), we classify SOEs or firms whose CEOs/chairmen were/are members of the CPC (Communist Party of China), NPC (National People's Congress), CPPCC (Chinese People's Political Consultative Conference), or government officials into PCs group, and other firms into Non-PCs group. The results, reported in Table 10 (Panel A), show that the coefficients on *DOI* are all positive and significant for both SOEs and Non-SOEs subsamples except Column (1). Panel B reveals that the coefficients on *DOI* are all insignificant (significant) when firms whose CEOs/chairmen are (not) members of the CPC, NPC, CPPCC, and government officers. More importantly, the coefficients on *DOI* are statistically larger in the Non-PCs subsample, as shown by the *p*-values of the tests of differences in coefficients reported at the bottom of each panel. Overall, these results support the rationale that the effect of D&O insurance on green innovation is weaker for firms with PCs.

6.1.3. The role of corporate governance

Another key proposition in our study is that D&O insurance can trigger management's moral hazard and make management self-interested by adopting self-serving behavior and engaging more in expropriating corporate resources (Chalmers et al., 2002), which has an adverse effect on firms' green innovation projects. Because firms with strong corporate governance are expected to reduce the likelihood of the management engaging in egregious behaviors at the expense of shareholders due to D&O insurance, we should expect that the increase in green innovation output is more pronounced for firms with better corporate governance. To test this conjecture, we use corporate governance as a partitioning variable and present the results of the subsample analysis in Table 11.

Following prior literature, we use institutional investors' shareholding and analyst coverage to measure the quality of corporate governance (e.g., Ali & Zhang, 2015; Yuan et al., 2016). As prior literature documents that institutional shareholdings play a positive role in corporate governance (e.g., An & Zhang, 2013; Callen & Fang, 2013), and firms followed by more analysts exhibit better corporate governance (e.g., Brennan & Subrahmanyam, 1995; Yu, 2008), we assign firms into high-quality corporate governance

Table 8
Alternative measures for green innovation.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	$y = PatentI_{t+2}$	$y = PatentU_{t+2}$	$y = PatentT_{t+2}$	$y = PatentI_{t+3}$	$y = PatentU_{t+3}$	$y = PatentT_{t+3}$
DOI	**0.071*****	**0.059*****	**0.078*****	**0.062*****	**0.054*****	**0.072*****
	(3.894)	**(3.183)**	**(3.485)**	**(3.236)**	**(2.751)**	**(3.021)**
Size	0.071***	0.086***	0.114***	0.075***	0.091***	0.119***
	(21.189)	(22.741)	(25.583)	(20.387)	(22.165)	(24.873)
Leverage	−0.026**	0.031**	−0.002	−0.032**	0.013	−0.022
	(–2.255)	(2.115)	(–0.132)	(–2.514)	(0.802)	(–1.187)
Age	−0.031***	−0.062***	−0.074***	−0.037***	−0.065***	−0.081***
	(–7.663)	(–11.916)	(–12.231)	(–8.067)	(–11.299)	(–12.124)
Profitability	−0.250***	−0.171***	−0.285***	−0.257***	−0.177***	−0.290***
	(–7.890)	(–4.140)	(–5.864)	(–7.479)	(–3.892)	(–5.458)
Tangible	−0.057***	−0.044**	−0.068***	−0.059***	−0.045**	−0.068***
	(–3.570)	(–2.278)	(–2.949)	(–3.461)	(–2.120)	(–2.758)
Tobin's Q	0.008***	0.005**	0.007**	0.009***	0.005**	0.008**
	(4.102)	(2.132)	(2.475)	(4.372)	(2.093)	(2.552)
Herfindahl	0.218	0.570***	0.526***	0.354**	0.667***	0.718***
	(1.630)	(5.951)	(3.474)	(2.313)	(5.729)	(4.081)
$Herfindahl^2$	−0.020	−0.382***	−0.209	−0.078	−0.388***	−0.251
	(–0.110)	(–3.995)	(–1.095)	(–0.404)	(–3.681)	(–1.261)
InstOwn	0.081***	0.102***	0.141***	0.099***	0.115***	0.164***
	(6.044)	(6.103)	(7.201)	(6.529)	(6.324)	(7.651)
Intercept	−1.506***	−1.877***	−2.447***	−1.605***	−1.978***	−2.594***
	(–19.604)	(–21.185)	(–23.672)	(–18.174)	(–19.847)	(–22.126)
Year-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
N	30,198	30,198	30,198	26,973	26,973	26,973
Adj. R^2	0.095	0.137	0.152	0.100	0.141	0.158

Notes: The table presents the results of the OLS regressions. The *t*-statistics are in parentheses below the regression coefficients and are calculated using Huber-White's (1980) heteroskedastic-consistent standard errors. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively, based on two-tailed tests. All continuous variables are winsorized at the 1st and 99th percentiles. Variables are defined in the Appendix.

Table 9
Cross-sectional test results regarding litigation risk.

Variables	$y = PatentI_{t+1}$		$y = PatentU_{t+1}$		$y = PatentT_{t+1}$	
	High	Low	High	Low	High	Low
DOI	0.054***	0.015	0.047**	0.038*	0.056**	0.042*
	(3.300)	(1.190)	(2.275)	(1.891)	(2.277)	(1.892)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Intercept	−1.214***	−1.001***	−1.576***	−1.586***	−2.072***	−2.023***
	(–15.002)	(–15.992)	(–14.601)	(–17.570)	(–16.342)	(–19.453)
Observations	17,137	16,501	17,137	16,501	17,137	16,501
Adj. R^2	0.101	0.094	0.145	0.140	0.154	0.158
The difference in *DOI* (*High* vs. *Low*)						
Differences	**0.039*****		0.009		**0.014***	
P-value	**0.000**		0.175		**0.083**	

Notes: In Table 9, the partitioning variable is *Litigation risk*. Firms operating in a province with a law index from Wang et al. (2019) equal to or greater than the sample median are assigned to the *High* litigation risk group, whereas the remaining firms are assigned to the *Low* litigation risk group. The table presents the results of the OLS regressions. The *t*-statistics are in parentheses below the regression coefficients and are calculated using Huber-White's (1980) heteroskedastic-consistent standard errors. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively, based on two-tailed tests. All continuous variables are winsorized at the 1st and 99th percentiles. Variables are defined in the Appendix.

group if their institutional shareholdings (or analyst coverage) are equal to or higher than the sample median; and assign other firms into low-quality corporate governance group. The results reported in Panels A and B (Table 11) show that the coefficients on *DOI* are positive and statistically significant in all columns except Column (2) of Panel A and Columns (2) and (6) of Panel B. More importantly, the coefficients on *DOI* are all statistically larger in the high-quality corporate governance subsample, as shown by the *p*-values of the tests of differences in coefficients reported at the bottom of each panel. Consistent with our expectation, these results indicate that the effect of D&O insurance on green innovation is more pronounced for firms with better corporate governance.

Table 10
Cross-sectional test results regarding political connections.

Panel A: Partition on whether a firm is a stated-owned-enterprise						
Variables	$y = PatentI_{t+1}$		$y = PatentU_{t+1}$		$y = PatentT_{t+1}$	
	SOEs	Non-SOEs	SOEs	Non-SOEs	SOEs	Non-SOEs
DOI	0.021	0.079***	0.041**	0.054**	0.037*	0.087***
	(1.461)	(4.257)	(2.133)	(2.429)	(1.664)	(3.228)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Intercept	−1.273***	−0.784***	−1.824***	−1.231***	−2.321***	−1.561***
	(–15.312)	(–13.415)	(–16.044)	(–15.524)	(–17.764)	(–16.832)
Observations	12,647	20,991	12,647	20,991	12,647	20,991
Adj. R^2	0.135	0.071	0.181	0.118	0.204	0.127
The difference in *DOI* (*SOEs* vs. *Non-SOEs*)						
Differences	**−0.058*** **		−0.013		**−0.050*** **	
P-value	**0.000**		0.125		**0.000**	
Panel B: Partition on whether a firm has a CEO/chairman with political identities						
Variables	$y = PatentI_{t+1}$		$y = PatentU_{t+1}$		$y = PatentT_{t+1}$	
	PCs	*Non–PCs*	*PCs*	*Non-PCs*	*PCs*	*Non-PCs*
DOI	−0.008	0.069***	−0.022	0.077***	−0.041	0.102***
	(–0.366)	(5.131)	(–0.813)	(4.353)	(–1.289)	(4.931)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Intercept	−1.398***	−0.982***	−1.866***	−1.319***	−2.414***	−1.773***
	(–13.389)	(–15.562)	(–11.469)	(–12.587)	(–12.870)	(–15.795)
Observations	11,647	21,991	11,647	21,991	11,647	21,991
Adj. R^2	0.091	0.096	0.138	0.137	0.148	0.153
The difference in *DOI* (*PCs* vs. *Non-PCs*)						
Differences	**−0.077*** **		**−0.099*** **		**−0.143*** **	
P-value	**0.000**		**0.000**		**0.000**	

Notes: In Panel A, the partitioning variable is *SOE* (stated-owned-enterprise). Firms ultimately controlled by the government are assigned to the *PCs* group, whereas the remaining firms are assigned to the *Non-PCs* group. In Panel B, the partitioning variable is the *CEO's/chairman's political identities*. Firms with a CEO/chairman was/is a member of the CPC (Communist Party of China), NPC (National People's Congress), CPPCC (Chinese People's Political Consultative Conference), or a government official are assigned to the *PCs* group and the rest are assigned to the *Non-PCs* group. The table presents the results of the OLS regressions. The *t*-statistics are in parentheses below the regression coefficients and are calculated using Huber-White's (1980) heteroskedastic-consistent standard errors. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively, based on two-tailed tests. All continuous variables are winsorized at the 1st and 99th percentiles. Variables are defined in the Appendix.

6.2. Potential outcome of improvement in green innovation related to D&O insurance

Corporate sustainability has a link to economic, social, and environmental capital (Dyllick & Hockerts, 2002). It is ideal for firms to leverage green innovation to achieve a win–win situation of green performance and firm value. However, green innovation plays a dual role in a firm's financial valuation, though it benefits the environment (Hart & Ahuja, 1996). On the one hand, green innovation can sustain competitive advantages and benefit firm performance (Albortmorant et al., 2016; Xie et al., 2019). On the other hand, green innovation increases business costs and decreases firm profits. Thus, it remains an open question whether the high green innovation performance brought by D&O insurance increases the firm value and leads to a win–win situation.

We explore the potential outcome of more green innovation related to green investment, i.e., firm valuation. We use the following model to assess the role of D&O insurance in the potential outcomes of green innovation:

$$Outcome_{i,t+2} = \beta 0 + \beta 1 \times DOI_{i,t+1} + \beta 2 \times GI_{i,t+1} + \beta 3 \times DOI_{i,t} \times GI_{i,t+1} + Controls_t + Year\ \ Fixed\ \ Effects + Industry\ \ Fixed\ \ Effects + \varepsilon_{i,t} \quad (3)$$

The *Outcome* measure *TQ* is Tobin's Q, widely used as a proxy for firm value. Since it takes time for the outcomes of green innovation to materialize, we adopt the two-year ahead *of Tobin's Q* as the dependent variable. Following prior research (e.g., Guedhami et al., 2014; He et al., 2017; Jiang et al., 2010), *Controls* indicate a series of control variables that take into account the firm financial and corporate governance characteristics, including *Size*, *Leverage*, *Profitability*, and *InstOwn*, which are defined before, as well as *Growth* (sales growth), *Board* (board size), and *BoardIndep* (board independence). The interaction term $DOI_t \times GI_{t+1}$ is our key variable of interest, and we expect its coefficient to be positive.

As shown in columns (1) to (3) of Table 12, the coefficients of $DOI_t \times GI_{t+1}$ are significantly positive at the 1% threshold level for all measures of *GI* (*PatentI*, *PatentU*, and *PatentIU*). Hence, D&O insurance not only advances firms to take green innovation but also enhances the benefits of green innovation on firm valuation, implying that D&O insurance helps achieve a win–win situation of

Table 11
Cross-sectional test results regarding corporate governance.

Panel A: Partition on firms' institutional shareholdings						
Variables	$y = PatentI_{t+1}$		$y = PatentU_{t+1}$		$y = PatentT_{t+1}$	
	High	Low	High	Low	High	Low
DOI	0.073***	−0.004	0.049**	0.044**	0.071***	0.037*
	(4.468)	(–0.320)	(2.412)	(2.332)	(2.947)	(1.725)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Intercept	−1.466***	−0.666***	−2.087***	−0.966***	−2.689***	−1.293***
	(–19.710)	(–11.074)	(–20.144)	(–11.574)	(–22.528)	(–13.263)
Observations	16,955	16,683	16,955	16,683	16,955	16,683
Adj. R^2	0.118	0.049	0.163	0.098	0.180	0.106
The difference in *DOI* (*High* vs. *Low*)						
Differences	**0.077*** **		0.005		**0.034** **	
P-value	**0.000**		0.220		**0.040**	
Panel B: Partition on firms' analyst following						
Variables	$y = PatentI_{t+1}$		$y = PatentU_{t+1}$		$y = PatentT_{t+1}$	
	High	*Low*	*High*	*Low*	*High*	*Low*
DOI	0.062***	0.008	0.049**	0.041*	0.067***	0.038
	(4.104)	(0.541)	(2.568)	(1.932)	(2.974)	(1.542)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Intercept	−1.308***	−0.952***	−1.903***	−1.162***	−2.435***	−1.685***
	(–22.066)	(–9.675)	(–23.575)	(–10.707)	(–25.975)	(–11.413)
Observations	21,279	12,359	21,279	12,359	21,279	12,359
Adj. R^2	0.110	0.058	0.154	0.099	0.169	0.109
The difference in *DOI* (*High* vs. *Low*)						
Differences	**0.054*** **		0.008		**0.029***	
P-value	**0.000**		0.285		**0.070**	

Notes: In Panel A, the partitioning variable is *InstOwn*. Firms with *InstOwn* equal to or greater than the sample median are assigned to the *High-quality* corporate governance group, and the rest are assigned to the *Low-quality* corporate governance group. In Panel B, the partitioning variable is *Analyst Following*. Firms with *Analyst Following* greater than the sample median are assigned to the *High-quality* corporate governance group, and the rest are assigned to the *Low-quality* corporate governance group. The table presents the results of the OLS regressions. The *t*-statistics are in parentheses below the regression coefficients and are calculated using Huber-White's (1980) heteroskedastic-consistent standard errors. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively, based on two-tailed tests. All continuous variables are winsorized at the 1st and 99th percentiles. Variables are defined in the Appendix.

environmental protection and firm value.

6.3. Economic mechanism: D&O insurance and managerial self-interest

Our findings indicate that companies with D&O insurance outperform those without in terms of green innovation performance. In this section, we uncover the economic mechanism through which D&O insurance influences firms' green innovation. Building upon the discussion in Section 2.2, we delve into a potential economic mechanism: D&O insurers introduce a supervisory effect on managerial self-interest behavior, which enhances the efficiency of resource allocation for green innovation and consequently fosters firms' green innovation efforts. However, due to the unavailability of direct observational data on D&O insurers' supervision of management, we resort to alternative data, specifically managerial self-interest data, to indirectly gauge the supervisory impact of D&O insurers on managerial behavior.

We opt for managerial self-interest data as the alternative dataset for several reasons. Firstly, D&O insurance serves as a liability cover purchased by firms to shield their directors and managers from legal liability stemming from their professional activities on behalf of the company (Chalmers et al., 2002). Acting as a safeguard against claims alleging breach of duties (Lin et al., 2011), D&O insurers are strongly motivated to oversee management behavior, including managerial self-interest, to mitigate potential losses from shareholder litigation (Core, 2000). Secondly, given that managers play a central role in the firm's resource allocation process, their self-interest behavior significantly influences decisions regarding project evaluation, such as investments in green innovation projects (Rutledge & Karim, 1999; Barker III & Mueller, 2002). In summary, the supervisory impact of D&O insurers can be indirectly observed through changes in managerial self-interest behavior, which in turn affects corporate green innovation. Therefore, based on this rationale, managerial self-interest is considered as the substitute variable for the supervisory effect of D&O insurers.

Specifically, we first examine the impact of D&O insurance on the tendency of managerial self-interest using the following model

Table 12
Potential outcome of improvement in green innovation related to D&O insurance.

Variable	$y = Tobin's\ Q_{t+2}$		
	(1)	(2)	(3)
DOI_t	0.207***	0.203***	0.184**
	(2.715)	(2.622)	(2.441)
$PatentI_{t+1}$	0.113**		
	(2.219)		
$\boldsymbol{DOI_t \times PatentI_{t+1}}$	**0.496*** **		
	(3.297)		
$PatentU_{t+1}$		0.059	
		(1.099)	
$\boldsymbol{DOI_t \times PatentU_{t+1}}$		**0.358*** **	
		(4.012)	
$PatentT_{t+1}$			0.038
			(0.969)
$\boldsymbol{DOI_t \times PatentT_{t+1}}$			**0.336*** **
			(3.732)
$Size_t$	−0.939***	−0.938***	−0.938***
	(–8.596)	(–8.500)	(–8.504)
$Leverage_t$	2.295***	2.291***	2.292***
	(4.149)	(4.146)	(4.143)
$Profitability_t$	5.311**	5.301**	5.303**
	(2.017)	(2.014)	(2.014)
$InstOwn_t$	0.837***	0.845***	0.844***
	(7.887)	(8.028)	(7.964)
$Growth_t$	−0.000**	−0.000**	−0.000**
	(–2.311)	(–2.336)	(–2.341)
$Board_t$	−0.593	−0.584	−0.586
	(–1.170)	(–1.154)	(–1.157)
$BoardIndep_t$	0.760	0.782	0.777
	(0.837)	(0.861)	(0.855)
Intercept	19.454***	19.404***	19.409***
	(7.059)	(6.983)	(6.997)
Year-fixed effects	Yes	Yes	Yes
Industry-fixed effects	Yes	Yes	Yes
N	27,335	27,335	27,335
Adj. R^2	0.011	0.011	0.011

Notes: The table presents the results of the OLS regressions. The *t*-statistics are in parentheses below the regression coefficients and are calculated using Huber-White's (1980) heteroskedastic-consistent standard errors. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively, based on two-tailed tests. All continuous variables are winsorized at the 1st and 99th percentiles. Variables are defined in the Appendix.

$$MFEE_{i,t} = \beta_0 + \beta_1 DOI_{i,t} + Controls + Fixed\ Effects + \varepsilon_{i,t} \quad (4)$$

where *MFEE* is the tendency of managerial self-interest (Ang et al., 2000), measured by the ratio of administrative expenses to sales in the current year. A higher *MFEE* value indicates a greater agency conflict between shareholders and management, and the more exacerbated presence of managerial self-interest. All control variables are the same as in Eq. (1). We also include industry- and year-fixed effects. Table 13, column (1) reports the results. As anticipated, the coefficient of *DOI* is negative and statistically significant, suggesting that D&O insurance restrains the managerial self-interest behavior of insured firms.

Second, we examine the impact of D&O insurance on the firms' green innovation. We use *DOI* in year *t* as the independent variable and *GI* (*PatentI*, *PatentU,* and *PatentT*) in year *t*+1 as dependent variables, respectively. All control variables are the same as in Eq. (1). We include industry- and year-fixed effects. Columns (2), (4), and (6) of Table 13 show that the coefficients on *DOI* are positive and statistically significant at the 1% threshold level, indicating that insured firms notably advance green innovation.

Third, we use the following model to estimate the direct effect of D&O Insurance on the firms' green innovation while controlling for the tendency of managerial self-interest (*MFEE*):

$$Ln\left(1 + GI_{i,t+1}\right) = \alpha_0 + \alpha_1 DOI_{i,t} + \alpha_2 MFEE_{i,t} + Controls + Fixed\ Effects + \varepsilon_{i,t} \quad (5)$$

Columns (3), (5), and (7) of Table 13 show that the coefficients of *DOI* remain significantly positive, indicating a positive and direct effect of D&O Insurance on green innovation. Furthermore, the coefficients on *MFEE* are all significantly negative in Columns (3), (5), and (7) of Table 13, indicating a negative relationship between managerial self-interest and D&O insurance.

In addition, to examine the mediating effect of managerial self-interest on the relation between D&O Insurance and firms' green

Table 13
Economic mechanism: D&O insurance and managerial self-interest.

Variable	$y = MFEE$	$y = PatentI_{t+1}$		$y = PatentU_{t+1}$		$y = PatentT_{t+1}$	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
DOI	−0.021***	0.098***	0.095***	0.117***	0.112***	0.150***	0.144***
	(-9.962)	(8.211)	(8.017)	(7.523)	(7.202)	(8.164)	(7.850)
MFEE			−0.122***		−0.262***		−0.306***
			(-11.811)		(-18.559)		(-17.718)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Intercept	0.205***	−0.090***	−0.066***	−0.159***	−0.106***	−0.212***	−0.149***
	(9.388)	(-14.280)	(-8.969)	(-17.866)	(-9.756)	(-18.863)	(-10.955)
Observations	33,629	33,629	33,629	33,629	33,629	33,629	33,629
Adj. R^2	0.069	0.051	0.052	0.091	0.094	0.098	0.101
Sobel tests for analysis of mediated relationships							
Sobel Z-value		**4.933*****		**8.777*****		**8.683*****	
(P-value)		0.000		0.000		0.000	

Note: The table presents the results of the OLS regressions. The *t*-statistics are in parentheses below the regression coefficients and are calculated using Huber-White's (1980) heteroskedastic-consistent standard errors. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively, based on two-tailed tests. All continuous variables are winsorized at the 1st and 99th percentiles. Variables are defined in the Appendix.

innovation, we compute the product of the coefficients from Eq. (4) (β_1) and Eq. (5) (α_2) and test the significance of the multiplicative coefficient ($\alpha_2 \times \beta_1$) using Sobel's test (Baron & Kenny, 1986).[4] The results of Sobel's tests in Table 13 indicate that the multiplicative coefficients are all significantly positive at the 1% threshold level, supporting the notion that the supervisory effect of D&O insurers on the managerial self-interest behavior is an important mechanism through which D&O Insurance affects firms' green innovation.

7. Conclusion

While several studies have examined different issues related to D&O insurance, little attention is paid to whether and how the insurance affects sustainable development. This study examines the relationship between D&O insurance and firms' green innovation, given that green innovation is considered an effective way to ease the burden of the environment and advance sustainable development.

We document that firms with D&O insurance significantly enhance green innovation performance, and this effect is more pronounced for firms exposed to a higher risk of litigation, without political connections, and with stronger corporate governance. We further show that insured firms' green innovation performance significantly advances firm value, implying that D&O insurance helps achieve a win-win situation between shareholder value and the environment. Further mechanism analysis shows that the supervision effect of D&O insurers on the managerial self-interest behavior is the underlying channel through which D&O Insurance affects firms' green innovation. Overall, our findings provide evidence supporting that D&O insurance motivates firms' directors and officers to actively pursue green innovation.

Our study adds to the growing literature on the consequences of D&O insurance from the perspective of environmental achievement on green innovation. At the same time, we extend prior studies on the determinants of firms' green innovation by identifying a new corporate governance factor that has a positive impact on firms' green innovation, namely D&O insurance. Our findings imply that an effective measure for firms to make a successful green transition is to encourage management to purchase D&O insurance. For regulators eager to achieve a win-win situation between economic development and the environment, the takeaway of our study is that it pays to introduce a mandatory environmental liability insurance system, especially in emerging market countries such as China.

Declaration of competing interest

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

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[4] See the example for Sobel's test (e.g., Pham et al., 2022).

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Appendix. Variable definitions

Variables	Definitions
Dependent variables	
PatentI	Natural logarithm of one plus the number of green invention patents
PatentU	Natural logarithm of one plus the number of green utility model patents
PatentT	Natural logarithm of one plus the total of green invention patents and green utility model patents
Variable of interest	
DOI	A dummy variable that is equal to 1 if a given firm purchases D&O insurance in the fiscal year, and 0 otherwise
Control variables	
Size	Firm size, measured by the natural logarithm of the fiscal year-end market value of equity
Leverage	Total liabilities divided by total assets at the fiscal year-end
Age	Firm age, measured by the natural logarithm of one plus the number of listing years of a given firm
Profitability	The ratio of earnings before interest, taxes, depreciation, and amortization divided by total assets, all measured at the fiscal year-end
Tangibility	Net property, plant, and equipment divided by total assets, all measured at the fiscal year-end
Tobin's Q	The ratio of market value to the book value of assets, all measured at the fiscal year-end
Herfindahl	The sum of the squared share of each firm in total (two-digit code for manufacturing industry, and one-digit code for other industries) industry sales
InstOwn	The percentage of shares outstanding held by institutional investors as of the fiscal year-end
Variables for robustness checks and additional tests	
ROA	Return on assets, calculated as the net profit divided by the book value of total assets at the fiscal year-end
Foreign	A dummy variable that is equal to 1 if the firm has issued H-shares or B-shares during the fiscal year, and 0 otherwise
SOE	A dummy variable that equals 1 if the ultimate controlling shareholder of a listed firm is the State in the fiscal year, and 0 otherwise
BoardIndep	The proportion of independent board directors
ManHold	The proportion of shares held by top executives
Violation	A dummy variable that equals 1 if the firm has a violation record in the fiscal year, and 0 otherwise
Balance	The ratio of the sum of the shareholdings held by the second to the fifth largest shareholders divided by the shareholdings held by the largest shareholder as of the fiscal year-end
BM	Book-to-market ratio, calculated as the book value of equity divided by the market value of equity in the fiscal year
MeanIndDOI	The mean incidence of D&O insurance purchases for firms in the same industry in the same year, excluding the concerned firm
Analyst Following	The natural logarithm of one plus the sum of the number of analysts
Growth	The difference between sales of the current and the prior year divided by prior year sales
Board	The natural logarithm of the number of board directors on a board
MFEE	The tendency of management self-interest, measured by the ratio of the administrative expenses to sales in the current year

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