# An Unexpected Serendipity: The Effect of D&O Insurance on Corporate Carbon Emissions in Manufacturing Industry

**Abstract**
This paper examines how directors' and officers' liability insurance (D&O insurance) affects corporate carbon emissions in the manufacturing industry. It shows that D&O insurance significantly and persistently lowers the carbon emission intensity of firms. The paper identifies two channels through which D&O insurance affects corporate environmental behaviors: fostering green innovation and enhancing internal control. Heterogeneity analysis finds that the emission-reducing effect of D&O insurance is stronger for firms in regions with lax environmental regulation and poor resource endowment; and stronger for firms with low executive compensation and high ownership-control divergence. The paper confirms the positive role of D&O insurance in providing managerial incentives and corporate governance for carbon emission reduction, and offers new implications and evidence for energy conservation practices in firms.
**Keywords:** carbon emissions, D&O insurance, managerial incentives, corporate governance

## 1. Introduction

The greenhouse gas emissions issue has consistently been at the forefront of global attention, with carbon emissions constituting a significant portion of these gases. The need for enhanced control over carbon emissions is not only a reflection of our evolving understanding of the patterns of human societal development but also an urgent requirement in our proactive response to global climate change. Despite concerted global efforts towards energy conservation and emission reduction, total greenhouse gas emissions witnessed a 1.4% increase in 2022, marking a historical peak. Emerging economies such as China and India have seen a substantial surge in their greenhouse gas emissions, with increases of 2.85 times and 1.70 times respectively. Data from the China Emission Accounts and Datasets (CEADs) reveals that China's carbon emissions in 2022 amounted to 11 billion tons, accounting for approximately 28.87% of global carbon emissions, thereby making it the world's leading carbon emitter. Consequently, devising effective strategies to reduce carbon emissions through policy guidance and technological innovation is an imperative challenge for China (Zhang et al., 2016; Zhang et al., 2020; Liu et al., 2022). In recent years, China has made significant strides in reducing carbon emissions. On the international front, China announced at the general debate of the 75th session of the United Nations General Assembly in September 2020 that it aims to reach peak carbon dioxide emissions by 2030 and strives to achieve carbon neutrality by 2060. Institutionally, China has successively established several work support institutions such as the National Coordination Group on Climate Change Response, the National Leading Group on Climate Change Response, and the National Center for Climate Change Strategy Research and International Cooperation. These institutions are tasked with formulating major strategies, policies, and measures for national climate

Electronic copy available at: https://ssrn.com/abstract=4630608

change response. In terms of policy, relevant departments have rolled out a series of macro policies that specify greenhouse gas emission control in sectors such as industry, transportation, construction, and energy. They have also successively initiated three batches of national low-carbon pilot cities and national carbon trading market construction. Enterprises, as key entities in achieving carbon emission reduction goals, are facing increasingly stringent environmental regulations and an urgent demand for low-carbon technologies (Balcombe et al., 2019; Yang et al., 2023). This has led to a gradual rise in business uncertainty (Ji et al., 2014; Lo & Shiah, 2016; Liao et al., 2023). While external policy regulation and market guidance have indeed reduced enterprises' carbon emissions to some extent, they do not necessarily stimulate enterprises' intrinsic motivation for energy conservation and emission reduction (Sun et al., 2023). Carbon reduction is a complex project (Touboulic et al., 2018; Tang et al., 2019; Wang et al., 2020a) that necessitates collaborative efforts from multiple parties. This includes changing development paradigms, adjusting organizational structures, investing in low-carbon technologies, eliminating outdated production capacities, etc., making it a large-scale and systemic task that requires continuous input of manpower, material resources, and financial resources (Li et al., 2018; Yin et al., 2022). According to upper echelon theory (Hambrick, 2007), executives play a pivotal role in corporate decision-making. If executives are willing or capable of implementing green behaviors, their top-down influence can directly shape the environmental strategy of the enterprise (Kanashiro & Rivera, 2019; Zhang & Jia, 2022), thereby facilitating the achievement of low-carbon goals. Therefore, incentivizing executives through institutional construction to make decisions that upgrade production and consequently reduce corporate carbon emissions is key to addressing this research question.

Directors and Officers (D&O) Liability Insurance, commonly referred to as D&O insurance, constitutes a specialized form of professional indemnity insurance procured by corporations. Its primary purpose is to shield directors and senior management from personal liability claims arising due to alleged negligence or misconduct during their tenure. In such cases, the insurer assumes responsibility for civil compensation costs. The origins of D&O insurance can be traced back to the United States during the economic upheaval of the 1930s. Gradually gaining prominence from the mid-1960s onward, it matured significantly between the 1970s and 1990s. In developed Western economies—such as the United States, United Kingdom, and Canada—D&O insurance has become a standard risk management strategy for publicly listed companies. Remarkably, over 95% of Fortune 500 companies have adopted such policies (Boubakri & Bouslimi, 2016). However, despite its widespread acceptance and application in mature capital markets, D&O insurance remains a contentious issue within academic circles. On the one hand, advocates of incentive theory contend that D&O insurance partially absolves directors, supervisors, and senior executives from personal liability. By mitigating risk, it encourages management to pursue production upgrades and innovation (Wang et al., 2020b) while simultaneously reducing attrition among high-performing executives (Li & Liao, 2021; Li et al., 2023). Furthermore, insurers provide professional external oversight, enhancing investor protection (Zou et al., 2008; Yuan et al., 2016; Habib et al., 2018). On the other hand, proponents of agency theory argue that purchasing D&O insurance weakens director and executive accountability (Baker & Griffith, 2019). This potential dilution of responsibility could invite opportunistic behavior (Chalmers et al., 2002; Lin et al., 2013). Paradoxically, it may increase overall corporate risk (Lin et al., 2011; Lin et al., 2013) and hinder industrial upgrades or green innovation, thereby perpetuating higher carbon emissions

Electronic copy available at: https://ssrn.com/abstract=4630608

levels. In the context of China, where D&O insurance adoption remains strikingly low (currently at 20.3% among listed companies as of 2022), substantial growth potential exists. This low adoption rate reflects either a lack of awareness or limited understanding of D&O insurance among Chinese listed companies. Consequently, exploring whether purchasing D&O insurance effectively reduces carbon emissions for listed firms becomes a critical research endeavor. Given China's persistent high carbon emission levels, this study aims to investigate whether this phenomenon correlates with insufficient emphasis on D&O insurance.

This study focuses on listed manufacturing companies in China from 2007 to 2022, examining the impact of purchasing D&O insurance on corporate carbon emissions. The findings suggest that the procurement of D&O insurance significantly attenuates the carbon emission intensity of firms. The efficacy of D&O insurance primarily manifests through the provision of effective incentives for corporate executives and robust enterprise supervision. This is achieved by fostering corporate green innovation activities, particularly substantive green innovation activities, and enhancing the level of corporate internal control. These findings align with existing research conclusions on effective strategies for reducing corporate carbon emissions. Specifically, the most efficacious avenue for enterprises to reduce carbon emissions involves undertaking green innovation, upgrading existing production lines, and augmenting energy utilization efficiency. Simultaneously, robust internal control facilitates corporate management in making decisions that are conducive to the long-term high-quality development of the enterprise. Heterogeneity analysis reveals that in regions with weaker legal regulation and lower resource endowment, D&O insurance can more effectively reduce corporate carbon emissions. From an enterprise perspective, in firms with lower CEO monetary compensation and lower separation of two rights, D&O insurance can more effectively reduce corporate carbon emissions.

This study makes several substantive contributions. First, it inaugurates an examination into the impact of D&O insurance on corporate carbon emissions, expanding the spectrum of factors affecting such emissions. Prevailing research primarily focuses on the efficacy of macro-level policy regulations (Jiang et al., 2021; Huo et al., 2022; Wang et al., 2023a) and market incentives (Zhang et al., 2020; Li & Wang, 2022; Shi et al., 2022) in reducing corporate carbon emissions, often overlooking the micro-level perspective that effectively motivates corporations to diminish their emissions. This study, rooted in the incentivizing effect of D&O insurance for corporate management, scrutinizes its effectiveness as a strategy for reducing corporate carbon emissions, thus introducing both novel theoretical underpinnings and empirical support for efficient carbon emission reduction. Second, this study extends the scope of research on the economic implications of D&O insurance. Contemporary academic discourse maintains two contrasting perspectives regarding the governance effects of D&O insurance. One posits a positive governance effect, characterized by the effective motivation of corporate executives to conscientiously fulfill their duties and make decisions conducive to long-term, high-quality corporate development (Wang & Wu, 2023). In contrast, the other perspective suggests that D&O insurance may impede efficient corporate governance, potentially increasing agency costs (Chung & Wynn, 2008; Lin et al., 2011; Li & Liao, 2014). This study, by examining D&O insurance through the lens of corporate carbon emission intensity, assesses its capacity to effectively fulfill its governance role. Consequently, this work contributes to the enrichment of existing research on the micro-level governance effects of D&O insurance, providing a foundational reference for the expansion of D&O insurance in the context of China. Third, this study delves

Electronic copy available at: https://ssrn.com/abstract=4630608

into the specific mechanisms by which D&O insurance impacts the reduction of corporate carbon emissions. These mechanisms encompass the incentive effect of promoting substantial green innovation activities within corporations and the supervisory effect of enhancing internal control levels. These channels illuminate how D&O insurance efficiently motivates corporate executives to make decisions favoring energy efficiency and emission reduction, thus unveiling the previously obscure workings of D&O insurance's impact. Fourth, this study conducts a comprehensive analysis of the differentiation in the influence of D&O insurance on the reduction of corporate carbon emissions, considering both regional macro-level factors and the micro-level characteristics of enterprises. This inquiry further elucidates the boundaries within which D&O insurance effectively exercises its incentivization effect, offering new policy recommendations and dependable evidence concerning the efficacious governance effects of D&O insurance and the reduction of corporate carbon emission intensity.

This paper is structured as follows. In Section 2, we present the theoretical framework and formulate the research hypotheses. Section 3 describes the data sources and explains the construction and treatment of the variables. Section 4 reports the main empirical findings. Section 5 addresses the issue of endogeneity and conducts several robustness checks. Section 6 explores the possible mechanisms underlying the observed relationships. Section 7 examines the heterogeneity of the effects across different subsamples. We conclude in Section 8 with a discussion of the implications.

## 2. Theoretical Foundation and Research Hypotheses

### 2.1 D&O insurance and corporate carbon emission reduction

Excessive energy consumption and carbon dioxide emissions are persistent challenges that require effective solutions. However, reducing carbon emissions is a complex and costly process that poses significant risks to enterprises (Kou et al., 2022). Achieving green and low-carbon development is a long-term goal that may entail short-term losses due to unpredictable factors such as capital expenditure, reduced economic performance, and investment failure (Ren et al., 2012; Hickey et al., 2019; Zhou et al., 2023). According to the upper echelon theory, executives' decisions are influenced by their attitudes, experiences, and values (Hambrick, 2007). They may exhibit risk aversion when considering corporate performance evaluation and their own career plans, leading them to adopt conservative or short-sighted strategies. In other words, although carbon reduction is beneficial to the enterprise, executives may give up or avoid investing in such projects due to the associated unknown risks.

D&O insurance provides a possible solution for the challenges faced by enterprises in reducing carbon emissions. D&O insurance transfers potential risks to insurance companies (Xia et al., 2023), relieving executives' worries about losses brought by their risky decisions. Prior studies have shown that D&O insurance provides protection for directors and officers against potential losses and alleviates the influences of uncertain risks faced in their professional activities on behalf of the enterprise (Jensen, 1993; Lin et al., 2011; Donelson et al., 2018). Firms insured have the insurers as the last card. This insurance guarantee relieves the risk aversion problem of the executives, improves their risk-bearing ability, and increases their incentives to actively play the subjective role and utilize personal talents (Jensen, 1993). Wang et al. (2020b) have demonstrated that D&O insurance increases the risk-taking ability of enterprises and enables them to invest more in innovation. Therefore, although reducing carbon emissions is accompanied by uncertain problems, D&O

Electronic copy available at: https://ssrn.com/abstract=4630608

insurance improves the risk-bearing ability of executives and encourages them to be bolder in promoting projects related to carbon reduction.

Informed by principal-agent theory, the separation of ownership and managerial rights introduces a divergence in interests between executives and stakeholders (Jensen and Meckling, 1976). This misalignment can manifest in executives prioritizing individual concerns, leading to issues such as moral hazard (Alchian and Demsetz, 1972) and adverse selection (Akerlof, 1970). Given the inherent challenges in realizing immediate economic gains from carbon reduction and the potential for increased costs and reduced net profit associated with green development initiatives (Sun et al., 2023), executives may exhibit reluctance to endorse carbon reduction efforts. This reluctance is further compounded by apprehensions about potential remuneration cuts and heightened accountability. The utilization of D&O insurance serves to intensify oversight by insurance entities, fostering an environment that aligns executive actions with the best interests of the enterprise. Consequently, this augmented scrutiny directs executive attention towards the reduction of carbon emissions. Previous studies have established the advantageous impact of external oversight from insurance entities on corporate operations (Chen et al., 2021; Tang et al., 2023; Wang et al., 2023b). The insurers, acting as regulators, influence executive conduct through the strategic pricing of insurance products. By evaluating potential risks associated with insured enterprises, insurance companies determine D&O premiums (Cao & Narayanamoorthy, 2014). Executives, seeking reduced insurance premiums, are incentivized to demonstrate heightened commitment to assuage insurer concerns. Concurrently, insurance companies, driven by the imperative to minimize payout obligations, assume an active monitoring role. Yermack (1996) empirically establishes the efficacy of insurers as monitors, motivating executives to exert greater efforts. Consequently, insurers effectively mitigate moral hazard and adverse selection concerns among executives, mitigate agency conflicts, harmonize shareholder and management interests (Aguir & Aguir, 2020), and curtail short-sighted or self-interested executive behaviors. Aligned with corporate objectives, executives, under the influence of insurers, are more inclined to prioritize carbon reduction initiatives, recognizing their positive impact on sustained corporate development. Furthermore, D&O insurance acts as a magnet for high-caliber management talent, with its adoption serving as a standard prerequisite for executive positions, particularly for those possessing advanced capabilities (Chen et al., 2016; Lin et al., 2022) in Western countries. Consequently, D&O insurance facilitates the continuous enhancement and refinement of the management team, bolstering internal managerial capacities and fortifying governance structures. High-quality management, characterized by a reduced propensity for short-sightedness and self-serving behavior, is more attuned to the adverse ramifications of environmental pollution on enterprises. Such management is also more likely to recognize opportunities inherent in environmentally conscious practices, endorsing the principles of green development. This top-down advocacy for green initiatives contributes to the transformative green reform of enterprises, fostering the reduction of carbon emissions.

Overall, based on the above observations, we propose our hypothesis as follows:

**H1: D&O insurance can reduce carbon emissions of enterprises.**

### 2.2 D&O insurance, green innovation, and corporate carbon emissions

#### 2.2.1 Green innovation

Amidst growing environmental concerns, heightened emphasis on green innovation has garnered widespread attention, emerging as a pivotal means to attain sustainable development (Du & Li, 2019; Zhang et al., 2023) and ameliorate

Electronic copy available at: https://ssrn.com/abstract=4630608

corporate pollution. Green innovation, characterized by its consideration of both economic and environmental benefits, assumes a significant role in compelling polluting enterprises to curtail carbon emissions. Its multifaceted impact encompasses reductions in energy consumption (Wurlod & Noailly, 2018), improvements in energy efficiency (Sun et al., 2019), and adjustments to energy structures (Ge et al., 2022), ultimately contributing to the reduction of carbon emissions (Xu et al., 2021). Existing literature affirms the adverse effects of innovation on firms' carbon emission intensity (Erdogan, 2021; Cheng & Yao, 2021; Lee et al., 2022c).

However, the pursuit of green innovation is accompanied by a heightened susceptibility to failure and uncertainties (Sun et al., 2023). Risk-averse executives often exhibit a reluctance to engage in such innovative projects. D&O insurance, however, serves to bolster the risk-bearing capacity of executives, alleviating their inherent aversion to risk by transferring potential losses to insurers (Xia et al., 2023). This enhancement in risk-bearing capability empowers management to embrace green innovation more readily. As emphasized by Zhang et al. (2023), the presence of D&O insurance correlates with heightened achievements in firms' green innovation endeavors and increased investments in environmental protection. The comprehensive coverage offered by D&O insurance functions as a protective shield against unforeseen losses arising from risky projects. This not only fosters a sense of security among risk-averse executives but also cultivates a more resilient attitude towards innovation failure, thereby encouraging proactive engagement in innovation and the pursuit of development opportunities for the company. Moreover, the continuous nature of green innovation necessitates ongoing investment (Liu & Wang, 2023). Recognizing the inherent crisis management capabilities of insurance companies, D&O insurance emerges as a strategic instrument in mitigating financial constraints faced by enterprises (Yang et al., 2021). Consequently, D&O insurance alleviates financial concerns associated with green innovation, thereby facilitating and promoting sustained green innovation activities within enterprises.

Therefore, based on the above observations, we propose our hypothesis as follows:

**H2a: D&O insurance promotes green innovation to reduce carbon emissions of enterprises.**

2.2.2 Green substantive innovation vs green strategic innovation

Prior research has delineated green innovation into two distinct categories—substantive green innovation and strategic green innovation—based on underlying motivations (Liu et al., 2021; Lian et al., 2022). These divergent motivations give rise to variations in green input, consequently influencing enterprises' green output and overall environmental performance (Lian et al., 2022). In this context, we aim to discern the types of green innovation that are more effectively promoted by D&O insurance for the explicit purpose of mitigating carbon emissions.

On one hand, substantive green innovation, characterized by its complexity, necessitates substantial support. Lian et al. (2022) posit that substantive innovation demands prolonged technological accumulation and considerable capital investment, thereby introducing heightened uncertainties. In the absence of D&O insurance, executives may exhibit a proclivity towards risk aversion, potentially impeding the advancement of substantive green innovation. Additionally, the benefits derived from substantive innovation are exclusive to firms (Truong et al., 2021). Consequently, we posit that D&O insurance is instrumental in fostering substantive green innovation within enterprises, thereby contributing to the reduction of carbon emissions.

On the other hand, strategic green innovation, being less intricate and requiring diminished financial and non-financial investment, comprises symbolic actions

Electronic copy available at: https://ssrn.com/abstract=4630608

designed primarily to manage stakeholder impressions, with the core organizational activities and strategic objectives remaining largely unaltered (Truong et al., 2021). Whether executives are insured or not, they may demonstrate a propensity to advocate for the implementation of strategic green innovation. However, strategic innovation primarily involves imitation or low-quality innovation in response to legal and regulatory requirements, representing a pursuit of speed and quantity with limited environmental benefits. Consequently, it does not contribute significantly to the reduction of carbon emissions by enterprises.

In summary, we posit that D&O insurance, in its capacity to incentivize risk-taking behavior, is more conducive to promoting substantive green innovation than its strategic counterpart. This leads us to formulate the following hypothesis:

**H2b: Compared with strategic green innovation, D&O insurance promotes substantive green innovation to reduce carbon emissions of enterprises.**

2.3 D&O insurance, internal control, and corporate carbon emissions

A robust internal control framework serves as an efficacious strategy for mitigating operational risks within enterprises, as evidenced by prior research (Ashbaugh-Skaife et al., 2009) and contributes to heightened operational efficiency (Petrovits et al., 2021), thereby curbing resource wastage and ultimately leading to a reduction in corporate carbon emissions. Simultaneously, a sound internal control mechanism plays a pivotal role in ameliorating information asymmetry within enterprises, fostering the alignment of interests between management and shareholders (Leuz et al., 2008). This alignment, in turn, diminishes the risk of managerial exploitation of corporate resources (Qi et al., 2017), prompting an increased managerial focus on sustainable development and, consequently, a decrease in carbon emissions. Furthermore, a well-established internal control system enhances the disclosure quality of information related to carbon emissions within enterprises (Chen, 2016), thereby facilitating societal oversight of the enterprises' efforts in energy conservation and emissions reduction.

Through D&O insurance, insurance companies assume an active and effective supervisory role in monitoring corporate governance (Wang & Wu, 2023). They engage in comprehensive pre-evaluation, in-process supervision, and post-compensation, functioning as independent external supervisors. Research by Li et al. (2022) indicates that D&O insurance positively influences corporate governance, aligning with the conclusion by O'Sullivan (1997) that D&O insurance has become an integral aspect of corporate governance. Leveraging their professional risk management expertise, insurance companies conduct thorough investigations and evaluations of enterprises, determining corresponding premiums while considering internal control vulnerabilities and risks (Hwang & Kim, 2018). Notably, firms characterized by inadequate governance incur higher premiums compared to well-governed counterparts (Yuan et al., 2016). This creates an incentive for firms with elevated premiums to bolster their internal control measures to mitigate insurance expenses. Moreover, insurance companies gather information from enterprises to formulate risk assessments, thereby contributing information to the market and establishing an effective monitoring mechanism for external parties (Yuan et al., 2016). Consequently, insured firms garner increased public attention, compelling them to enhance internal controls.

In light of the foregoing observations, we propose the following hypothesis:

**H3: D&O insurance improves internal control quality to reduce carbon emissions of enterprises.**

Electronic copy available at: https://ssrn.com/abstract=4630608

## 3. Research Design

3.1 Sample selection and data source

Our analysis concentrates on Chinese A-share manufacturing firms listed on the Shanghai and Shenzhen stock exchanges over the period spanning 2008 to 2021. Given that the manufacturing sector bears the primary responsibility for carbon emissions, we direct our attention to this industry. The implementation of new Chinese accounting standards in 2007 prompts the initiation of our sample period in 2008, ensuring the avoidance of any potential influence from the transition between old and new accounting standards on our findings. Sample selection adheres to rigorous procedures: (1) exclusion of firms with special treatment status; (2) omission of insolvent firms (those with total liabilities surpassing total assets) due to their potential pursuit of D&O insurance for compensation purposes; and (3) elimination of firms with missing values. Our final sample encompasses 21,950 firm-year observations, of which 1,695 observations involve the purchase of D&O insurance. Data are primarily sourced from the CSMAR database, CNRDS database, China Energy Statistical Yearbook, and China Industrial Economic Statistical Yearbook. To enhance data robustness, we employ winsorization, adjusting all continuous variables at the 1st and 99th percentiles. Further details regarding sample selection are presented in Table 1.

**Table 1 Sample selection**

| | |
|---|---|
| Manufacturing firms listed in Shanghai and Shenzhen Stock Exchanges from 2008 to | 26,167 |
| Less: | |
| Observations with special treatment status | (1,005) |
| Observations with getting insolvent | (63) |
| Observations with missing variables | (3,149) |
| Final sample | 21,950 |

3.2 Empirical model and variables

3.2.1 Model setting

To test the efficacy of D&O insurance on carbon emissions, we construct the following regression model:

$$CO2_{i,t}=\alpha+\beta DOI_{i,t}+\sum Controls+\sum Year+\sum Ind+\varepsilon_{i,t} \quad (1)$$

Where *i* and *t* refer to the firm and year respectively. *CO2* is the dependent variable measuring corporate carbon emission intensity. *DOI* is the independent variable measuring whether the firm is insured in a given year. *Controls* are the control variables. *Year* and *Ind* are dummy variables controlling year and industry fixed effect. We fix industry rather than firm effect because the whether the company purchases D&O insurance does not change so much within the sample period. We focus on the different effect of D&O insurance purchase in different companies. However, we also fix the firm effect in the robustness checks to verify the result.

3.2.2 Dependent variable: carbon emission intensity (*CO2*)

Studies on carbon emission reduction at the firm level in China are nascent, lacking standardized principles mandating the disclosure of carbon emission information by listed firms. Consequently, there is a dearth of a uniform methodology for computing a firm's carbon emission intensity. Drawing inspiration from recent research, including Lee et al. (2022), in the Chinese context, we operationalize carbon

Electronic copy available at: https://ssrn.com/abstract=4630608

emission intensity (*CO2*) as the ratio of carbon emissions to revenue. This measurement is defined and computed in the following manner:

$$Carbon\ emission_{i,t}=industrial\ energy\ consumption_{j,t}\times Carbon\ dioxide\ conversion\ factor\times Operating\ cost_{i,t}/industrial\ Operating\ cost_{j,t} \quad (2)$$

$$CO2_{i,t}=carbon\ emission_{i,t}/operating\ income_{i,t} \quad (3)$$

Where *i, j* and *t* refer to the firm, industry and year respectively. In order to measure *CO2*, we first calculate corporate carbon emission in a given year (*Carbon emission*) by model (2), where *industrial energy consumption* is the total energy consumption of a given industry in a given year, including coal, petroleum, natural gas, hydro power, nuclear power, et al.; *Carbon dioxide conversion factor* is an official factor designed to calculate carbon emission per energy consumption; *operating cost* is the total operating costs of a firm in a given year; *industrial operating cost* is the total operating costs of a given industry in a given year. We then calculate *CO2* by model (3), which equals the ratio of a firm's carbon emission in a given year to its operating income. Data for *industrial energy consumption* comes from China Energy Statistical Yearbook, *industrial operating cost* comes from China Industrial Economic Statistical Yearbook, *operating cost* and *operating income* come from CSMAR database, and *Carbon dioxide conversion factor* equals 2.493.

3.2.3 Independent variable: D&O insurance (*DOI*)

Chinese firms are not obligated to divulge information regarding D&O insurance premiums and coverage amounts. Therefore, consistent with established precedent in the literature (Zou et al., 2008; Lin et al., 2011; Yuan et al., 2016; Li et al., 2022; Zhang et al., 2023), we employ a binary variable, denoted as *DOI*, to proxy for the presence of D&O insurance. This dummy variable assumes a value of 1 if a firm opts for D&O insurance within a given year and 0 otherwise. The data pertaining to D&O insurance are sourced from the CNRDS database.

3.2.4 Control variables

Drawing from established literature (Zou et al., 2008; Lin et al., 2011; Yuan et al., 2016), our model incorporates the following control variables: (1) Variables of financial characteristics. *Size* represents the firm size, which is measured by the natural logarithm of total assets. *Lev* is to measure the firm's financial leverage, which equals the ratio of total liabilities to total assets. *ROA* is firm profitability, which is measured by the ratio of net profit to total assets. *Growth* represents growth ability of the firm and is measured by the growth rate of operating income. *Cfo* is to measure net operating cash flow, which is calculated by the ratio of net operating cash flow to total assets. *Epe* is the environmental protection input, which equals to the ratio of environment-related expense to operating cost. *BM* is the ratio of the firm's book value to its market value. (2) Variables of corporate governance characteristics. *Director* measures the board size, which equals the number of directors in a board. *Idr* is to measure the proportion of independent directors in a board, which equals the ratio of the number of independent directors to the number of directors. *Dual* is a dummy variable equals 1 if CEO and chairman are the same individual and 0 otherwise. *TOP1* is measured by the percentage ownership of the largest shareholder. *Gqz* represents the degree of equity balance, which equals the ratio of the sum of shareholding ratios from the second to the fifth largest shareholders to the shareholding ratio of the largest shareholder. *SOE* is a dummy variable equals 1 if the ultimate controller is a state-owned enterprise or a government department and 0

Electronic copy available at: https://ssrn.com/abstract=4630608

otherwise. *Age* is measured by the natural logarithm of the years since the firm was listed plus 1. (3) Variable of regional development level. *GDPgrowth* is to measure the regional economic development, which equals the growth rate of gross regional product. Besides, year fixed effect (*Year*) and industry fixed effect (*Ind*) are also controlled. All data come from CSMAR database. All variables are defined in Table 2.

**Table 2 Variable definition**

| Variable name | Variable symbol | Definition |
|---|---|---|
| Carbon emission intensity | *CO2* | Carbon emission divided by operating income, where carbon emission= (industrial energy consumption×carbon dioxide conversion factor×operating cost)/industrial operating cost. |
| D&O insurance | *DOI* | A dummy variable that equals 1 if a firm purchase D&O insurance in a given year, and 0 otherwise. |
| Firm size | *Size* | Natural logarithm of total assets |
| Financial leverage | *Lev* | Total liabilities divided by total assets |
| Profitability | *ROA* | Net profit divided by total assets |
| Growth ability | *Growth* | (Operating income in year t - operating income in year t-1)/operating income in year t-1 |
| Operating cash flow | *Cfo* | Net operating cash flow divided by total assets |
| Environmental protection input | *Epe* | Environment-related expenses divided by operating cost |
| Book to market ratio | *BM* | Book value divided by market value |
| Board size | *Director* | The number of directors in a board |
| Proportion of independent directors | *Idr* | The number of independent directors divided by the number of directors |
| Duality | *Dual* | A dummy variable that equals 1 if CEO and chairperson are the same individual and 0 otherwise |
| Ownership concentration | *Top1* | The shareholding ratio of the largest shareholder |
| Equity balance | *Gqz* | The sum of shareholding ratios from the second to the fifth largest shareholders divided by the shareholding ratio of the largest shareholder |
| Property nature | *SOE* | A dummy variable that equals 1 if the ultimate controller of a firm is a state-owned enterprise or a government department, and 0 otherwise |
| Firm age | *Age* | Natural logarithm of the number of years since the firm is listed plus 1 |
| Regional development | *GDPgrowth* | (Gross regional product in year t - gross regional product in year t-1)/gross regional product in year t-1 |

# 4. Empirical Analysis

## 4.1 Descriptive statistics

Table 3 presents the descriptive statistics for the variables examined in our study. The mean of *DOI* indicates that 7.7% of our observations opt for D&O insurance, a proportion notably lower than that observed in developed countries (Chung & Wynn, 2008; Chen et al., 2016). However, it closely aligns with findings from prior studies focusing on Chinese listed firms (Li et al., 2022; Zhang et al., 2023). This suggests that the practice of purchasing D&O insurance is not widely embraced among listed firms in China, indicating a lack of pervasive awareness. The mean value of *CO2* stands at 0.627, implying that, on average, for every unit increase in revenue, a firm concurrently increases its carbon emissions by 0.627 units. The standard deviation of

Electronic copy available at: https://ssrn.com/abstract=4630608

*CO2* is 0.872, underscoring the substantial variability in carbon emission intensity among listed manufacturing firms. Descriptive statistics for other variables exhibit no pronounced deviations from findings in prior literature.

**Table 3 Descriptive statistics**

| Variables | N | Mean | SD | Min | P25 | P50 | P75 | Max |
|---|---|---|---|---|---|---|---|---|
| *CO2* | 21,950 | 0.627 | 0.872 | 0.078 | 0.126 | 0.241 | 0.696 | 5.357 |
| *DOI* | 21,950 | 0.077 | 0.267 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 |
| *Size* | 21,950 | 21.983 | 1.152 | 19.862 | 21.138 | 21.832 | 22.638 | 25.440 |
| *Lev* | 21,950 | 0.404 | 0.194 | 0.055 | 0.249 | 0.399 | 0.547 | 0.865 |
| *ROA* | 21,950 | 0.039 | 0.062 | -0.230 | 0.014 | 0.039 | 0.071 | 0.204 |
| *Growth* | 21,950 | 0.174 | 0.362 | -0.482 | -0.014 | 0.119 | 0.278 | 2.189 |
| *Cfo* | 21,950 | 0.049 | 0.068 | -0.144 | 0.010 | 0.047 | 0.088 | 0.242 |
| *Epe* | 21,950 | 0.025 | 0.089 | 0.000 | 0.000 | 0.000 | 0.000 | 0.615 |
| *BM* | 21,950 | 0.589 | 0.235 | 0.114 | 0.410 | 0.586 | 0.763 | 1.125 |
| *Director* | 21,950 | 8.494 | 1.573 | 5.000 | 7.000 | 9.000 | 9.000 | 14.000 |
| *Idr* | 21,950 | 0.374 | 0.053 | 0.333 | 0.333 | 0.333 | 0.429 | 0.571 |
| *Dual* | 21,950 | 0.303 | 0.460 | 0.000 | 0.000 | 0.000 | 1.000 | 1.000 |
| *Top1* | 21,950 | 33.601 | 14.054 | 8.930 | 22.790 | 31.570 | 42.569 | 71.560 |
| *Gqz* | 21,950 | 0.738 | 0.600 | 0.028 | 0.268 | 0.583 | 1.050 | 2.777 |
| *SOE* | 21,950 | 0.304 | 0.460 | 0.000 | 0.000 | 0.000 | 1.000 | 1.000 |
| *Age* | 21,950 | 2.055 | 0.795 | 0.000 | 1.386 | 2.197 | 2.708 | 3.296 |
| *GDPgrowth* | 21,950 | 0.100 | 0.054 | -0.082 | 0.072 | 0.096 | 0.123 | 0.244 |

This table reports descriptive statistics on carbon emission intensity, D&O insurance, and control variables for the sample in 2008-2021.

4.2 Multivariate regression results

In this section, we scrutinize the impact of D&O insurance (*DOI*) on carbon emission intensity (*CO2*) using Model (1). The ensuing results are delineated in Table 4. In Column (1), we exclusively incorporate year and industry dummies, while in Column (2), we augment the model with a comprehensive set of control variables. The coefficients of D&O insurance (*DOI*) in the table exhibit negative and statistically significant values at the 10% and 1% significance levels (β=-0.025, t=-1.82; β=-0.038, t=-2.86), implying that D&O insurance exerts a negative influence on the carbon emission intensity of manufacturing firms—a finding in line with our hypothesized expectations. Moreover, the observed effect is economically substantive. A one-standard-deviation rise in *DOI* (0.267) is linked to a 1.01-basis-point reduction (-0.038×0.267) in *CO2*, translating to approximately 4.19% of the sample median (0.241) and 1.61% of the sample mean (0.627). Consequently, we establish a statistically and economically significant inverse association between D&O insurance and carbon emission intensity.

Regarding the control variables, carbon emission intensity (*CO2*) exhibits a significantly positive correlation with ownership concentration (*Top1*) and equity balance (*Gqz*). In contrast, it displays a significant negative association with firm profitability (*ROA*), growth ability (*Growth*), net operating cash flow (Cfo), environmental protection input (*Epe*), and the book-to-market ratio (*BM*). The coefficients for the remaining variables are statistically insignificant.

**Table 4 D&O insurance and carbon emission intensity**

| | (1) | (2) |
|---|---|---|
| | *CO2* | *CO2* |

Electronic copy available at: https://ssrn.com/abstract=4630608

| | | |
|---|---|---|
| *DOI* | -0.025* | -0.038*** |
| | (-1.82) | (-2.86) |
| *Size* | | -0.002 |
| | | (-0.36) |
| *Lev* | | 0.043 |
| | | (1.58) |
| *ROA* | | -1.053*** |
| | | (-12.51) |
| *Growth* | | -0.024*** |
| | | (-2.87) |
| *Cfo* | | -0.205*** |
| | | (-3.52) |
| *Epe* | | -0.108** |
| | | (-2.25) |
| *BM* | | -0.046** |
| | | (-2.06) |
| *Director* | | -0.003 |
| | | (-1.10) |
| *Idr* | | 0.040 |
| | | (0.42) |
| *Dual* | | 0.003 |
| | | (0.37) |
| *Top1* | | 0.001** |
| | | (2.49) |
| *Gqz* | | 0.021* |
| | | (1.87) |
| *SOE* | | 0.008 |
| | | (0.76) |
| *Age* | | 0.010 |
| | | (1.27) |
| *GDPgrowth* | | 0.068 |
| | | (0.67) |
| *Constant* | 0.649*** | 0.663*** |
| | (22.56) | (7.01) |
| *Year* | Yes | Yes |
| *Ind* | Yes | Yes |
| Obs. | 21950 | 21950 |
| Adj. $R^2$ | 0.801 | 0.808 |

This table reports the results from OLS regressions of the impact of D&O insurance on carbon emission intensity. Reported in parentheses are t-values based on robust standard errors clustered at the firm level. *, **, *** represent statistically significantly different from zero at the 0.10, 0.05, and 0.01 level, respectively.

## 5. Robustness Tests and Endogeneity Discussion

In this section, we perform several robustness tests to examine the stability of our results and alleviate endogeneity concerns.

5.1 Changing the measurement of the dependent variable

The metric employed for carbon emission intensity signifies the magnitude of a firm's carbon emissions, providing a static representation without capturing changes in emission intensity. To address this limitation, we substitute carbon emission intensity (*CO2*) with the change in carbon emission intensity (*DeltaCO2*) and reevaluate the baseline regression. Notably, if a firm reduces its carbon emission

Electronic copy available at: https://ssrn.com/abstract=4630608

intensity in a given year, *DeltaCO2* should manifest as negative. Column (1) in Table 5 presents the results of these regression analyses. The relationship between *DeltaCO2* and *DOI* demonstrates a statistically significant negative association at the 1% significance level (β=-0.013, t=-3.21), aligning with our primary conclusion.

5.2 Changing the measurement of the independent variable

We redefine D&O insurance (*lnDOI*) as the temporal duration a firm maintains D&O insurance. This duration is represented by the natural logarithm of the total number of years a firm has held D&O insurance since the initiation of our research in 2008 plus 1. The findings, detailed in Column (2) of Table 5, reveal a significantly negative coefficient for *lnDOI* at the 5% significance level (β=-0.021, t=-2.21). This outcome underscores the robustness of our conclusion.

5.3 Adjusting sample selection procedures

Companies procure insurance with the primary objective of risk mitigation (Mayers & Smith, 1982). Consequently, we refine our analysis by excluding observations characterized by negative net profits in a given year, those with less than one year of listing, and those issuing B or H-shares, as these factors may contribute to heightened risks. The outcomes, detailed in Column (3) of Table 5, reveal a statistically significant negative association between D&O insurance (*DOI*) and carbon emission intensity (*CO2*) at the 10% significance level (β=-0.023, t=-1.87). This reaffirms the robustness of our primary findings.

5.4 Adding additional control variables

D&O insurance is recognized for its role in reinforcing external oversight mechanisms (Mayer & Smith, 1982), and the effectiveness of such external supervision can impact corporate behaviors, potentially influencing a firm's commitment to environmentally responsible practices. To account for this, we introduce additional controls for external oversight by incorporating analyst coverage (*Ana*) and institutional influence (*Ins*). In line with Yu (2008), we employ the natural logarithm of the number of analysts making forecasts about a firm in a given year plus 1 to quantify analyst coverage (*Ana*). Following the methodology of Hartzell and Starks (2003), we use the shareholding ratio of institutional investors to gauge institutional influence (*Ins*). The results, presented in Column (4) of Table 5, maintain the significance of the negative association between D&O insurance (*DOI*) and carbon emission intensity (*CO2*) at the 5% significance level (β=-0.038, t=-2.17). However, the coefficients for analyst coverage (*Ana*) and institutional influence (*Ins*) are found to be statistically insignificant. These outcomes underscore the robustness of our findings.

**Table 5 Robustness tests**

| | Replacing dependent variable | Replacing independent variable | Adjusting selection procedures | Adding additional control variables |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| | *DeltaCO2* | *CO2* | *CO2* | *CO2* |
| *DOI* | -0.013*** | | -0.023* | -0.038** |
| | (-3.21) | | (-1.87) | (-2.17) |
| *lnDOI* | | -0.021** | | |
| | | (-2.21) | | |
| *Ana* | | | | -0.002 |
| | | | | (-0.35) |
| *Ins* | | | | 0.000 |
| | | | | (0.37) |

Electronic copy available at: https://ssrn.com/abstract=4630608

| | | | | |
|---|---|---|---|---|
| *Size* | 0.021*** | -0.003 | -0.008 | 0.004 |
| | (13.59) | (-0.56) | (-1.45) | (0.56) |
| *Lev* | -0.080*** | 0.044 | 0.059** | 0.081*** |
| | (-9.57) | (1.63) | (2.09) | (2.59) |
| *ROA* | -0.911*** | -1.049*** | -0.802*** | -1.100*** |
| | (-23.50) | (-12.47) | (-6.28) | (-9.01) |
| *Growth* | -0.087*** | -0.024*** | -0.016** | -0.011 |
| | (-13.84) | (-2.85) | (-2.01) | (-1.18) |
| *Cfo* | -0.032 | -0.206*** | -0.170*** | -0.073 |
| | (-1.37) | (-3.54) | (-2.58) | (-1.01) |
| *Epe* | -0.003 | -0.106** | -0.092** | -0.142** |
| | (-0.29) | (-2.21) | (-1.97) | (-2.43) |
| *BM* | -0.059*** | -0.046** | 0.000 | -0.065** |
| | (-8.35) | (-2.02) | (0.01) | (-2.16) |
| *Director* | -0.001 | -0.003 | -0.004 | -0.006* |
| | (-1.03) | (-1.12) | (-1.14) | (-1.67) |
| *Idr* | -0.043* | 0.039 | 0.037 | 0.019 |
| | (-1.79) | (0.42) | (0.36) | (0.18) |
| *Dual* | 0.006** | 0.003 | 0.008 | -0.000 |
| | (2.46) | (0.40) | (0.99) | (-0.05) |
| *Top1* | 0.000*** | 0.001** | 0.001** | 0.001 |
| | (3.74) | (2.44) | (2.02) | (1.54) |
| *Gqz* | 0.006** | 0.019* | 0.013 | 0.016 |
| | (2.21) | (1.79) | (1.27) | (1.12) |
| *SOE* | -0.012*** | 0.007 | 0.009 | 0.013 |
| | (-4.20) | (0.67) | (0.85) | (1.07) |
| *Age* | -0.024*** | 0.009 | 0.014 | -0.002 |
| | (-11.48) | (1.22) | (1.53) | (-0.19) |
| *GDPgrowth* | 0.047 | 0.068 | 0.032 | 0.069 |
| | (1.30) | (0.66) | (0.36) | (0.51) |
| *Constant* | -0.354*** | 0.685*** | 0.743*** | 0.581*** |
| | (-12.03) | (7.26) | (7.19) | (4.84) |
| *Year* | Yes | Yes | Yes | Yes |
| *Ind.* | Yes | Yes | Yes | Yes |
| Obs. | 21778 | 21950 | 18285 | 15563 |
| Adj. $R^2$ | 0.314 | 0.808 | 0.823 | 0.806 |

This table reports the robustness tests of the impact of D&O insurance on carbon emission intensity. In Column (1), we replace the measurement of the dependent variable. In Column (2), we replace the measurement of the independent variable. In Column (3), we add additional sample selection procedures. In Column (4), we add additional control variables. Reported in parentheses are t-values based on robust standard errors clustered at the firm level. *, **, *** represent statistically significantly different from zero at the 0.10, 0.05, and 0.01 level, respectively.

## 5.5 Addressing self-selection bias

A firm's decision to acquire D&O insurance may exhibit non-random characteristics, introducing the possibility of self-selection bias. To address potential endogeneity concerns, we employ a treatment effect model (Maddala, 1983) to scrutinize our results. In the initial step, we utilize a probit model to estimate a firm's propensity to procure D&O insurance, with the duration of insurance (*DOI*) serving as the dependent variable. Consistent with Chung & Wynn (2008), Yuan et al. (2016), and Zhang et al. (2023), we incorporate the following variables as determinants influencing a firm's decision to acquire D&O insurance: *Crosslist* (a binary variable

Electronic copy available at: https://ssrn.com/abstract=4630608

equalling 1 if a firm is cross-listed, and 0 otherwise); *Violation* (a binary variable equalling 1 if a firm has a violation record in a given year, and 0 otherwise); *Mshr* (the proportion of managerial ownership); *Moversea* (a binary variable equalling 1 if directors, supervisors, or management have overseas backgrounds, and 0 otherwise); *Female* (the proportion of female management). The probit model is specified as follows:

$$DOI_{i,t}=\beta_0+\beta_1 Crosslist_{i,t}+\beta_2 Violation_{i,t}+\beta_3 Mshr_{i,t}+\beta_4 Moversea_{i,t}+\beta_5 Female_{i,t} +\sum Controls+\sum Year+\sum Ind+\varepsilon_{i,t} \quad (4)$$

In the second step, we incorporate the inverse Mills ratio (*IMR*) generated in the first step to alleviate potential sample selection bias. The model, along with all other control variables, remains consistent with Model (1).

The regression results are presented in Table 6. Column (1) displays the results of the first step, while Column (2) reveals the outcomes of the second step. In Column (1), it is observed that *Crosslist* and *Moversea* exhibit significant and positive effects on a firm's decision to acquire D&O insurance, while *Mshr* demonstrates a significant and negative impact. *Violation* and *Female*, however, do not exhibit significant impacts. These findings align with prior research (Yuan et al., 2016; Zhang et al., 2023). In Column (2), the coefficient of *IMR* is found to be significantly negative at the 10% significance level (β=-0.033, t=-1.78), suggesting that unobservable factors motivating firms to obtain D&O insurance are inversely related to corporate carbon emission intensity. Importantly, the coefficient of *DOI* remains significantly negative at the 1% level (β=-0.039, t=-2.66). The variance inflation factor is 2.79, indicating the absence of significant multicollinearity issues. These results affirm the robustness of our findings.

**Table 6 Self-selection bias**

| | (1)<br>*DOI* | (2)<br>*CO2* |
|---|---|---|
| *DOI* | | -0.039*** |
| | | (-2.66) |
| *Crosslist* | 0.772*** | |
| | (5.76) | |
| *Violation* | -0.002 | |
| | (-0.04) | |
| *Mshr* | -0.005** | |
| | (-2.45) | |
| *Moversea* | 0.298*** | |
| | (5.14) | |
| *Female* | 0.003 | |
| | (1.13) | |
| *IMR* | | -0.033* |
| | | (-1.78) |
| *Size* | 0.133*** | -0.007 |
| | (3.40) | (-1.16) |
| *Lev* | 0.338* | 0.028 |
| | (1.67) | (1.02) |
| *ROA* | -0.980** | -1.026*** |
| | (-2.55) | (-12.02) |
| *Growth* | -0.013 | -0.022** |
| | (-0.28) | (-2.57) |

Electronic copy available at: https://ssrn.com/abstract=4630608

| | | |
|---|---|---|
| *Cfo* | 0.294 | -0.204*** |
| | (0.88) | (-3.42) |
| *Epe* | -0.627** | -0.093* |
| | (-2.43) | (-1.91) |
| *BM* | -0.327** | -0.032 |
| | (-2.47) | (-1.36) |
| *Director* | 0.013 | -0.004 |
| | (0.67) | (-1.22) |
| *Idr* | 0.734 | 0.033 |
| | (1.34) | (0.34) |
| *Dual* | -0.107* | 0.005 |
| | (-1.77) | (0.68) |
| *Top1* | 0.003 | 0.001** |
| | (0.99) | (2.03) |
| *Gqz* | 0.192*** | 0.013 |
| | (2.91) | (1.13) |
| *SOE* | 0.246*** | 0.004 |
| | (2.72) | (0.34) |
| *Age* | 0.153*** | 0.002 |
| | (2.83) | (0.24) |
| *GDPgrowth* | 0.508 | 0.053 |
| | (0.87) | (0.52) |
| *Constant* | -6.058*** | 0.879*** |
| | (-7.53) | (5.53) |
| *Year* | Yes | Yes |
| *Ind.* | Yes | Yes |
| Obs. | 21443 | 21443 |
| Adj. R2 | | 0.809 |
| Pseudo $R^2$ | 0.225 | |

This table reports the impact of D&O insurance on carbon emission intensity using treatment effect model. Column (1) reports the results of the first-step, while Column (2) reports the results of the second-step. Reported in parentheses are t-values based on robust standard errors clustered at the firm level. *, **, *** represent statistically significantly different from zero at the 0.10, 0.05, and 0.01 level, respectively.

## 5.6 PSM-DID approach

There might exist a reverse causal link between D&O insurance and carbon emission intensity, along with potential nonlinear impacts of control variables. The Propensity Score Matching (PSM) method allows for a comparison between D&O insured firms and a set of non-insured firms, considering the nonlinear impacts of observable variables, thereby facilitating a clearer attribution of the effect of D&O insurance (Bowen et al., 2010). Following prior research (Yuan et al., 2016; Wang et al., 2020; Zhang et al., 2023), we employ the PSM approach, supplemented by the Difference-in-Difference (DID) method, to provide additional evidence and mitigate potential interference from expected effects on the outcomes, as suggested by Li et al. (2022). The DID approach aids in establishing causality and alleviates concerns regarding reverse causality (Wang et al., 2020).

Specifically, we begin by excluding observations that continuously purchase D&O insurance throughout our research period and those that cease purchasing D&O insurance during the research period. Our sample for the PSM-DID test comprises observations that are never insured during the entire period and those that commence and persist in purchasing D&O insurance within the period. We employ a one-to-one

Electronic copy available at: https://ssrn.com/abstract=4630608

non-replacement nearest-neighbor matching, selecting all control variables in Model (1) as covariates for the matching process. To ensure satisfactory matching, we initially test whether the means of the covariates differ between the treatment and matched control firms. The results, presented in Table 7, indicate no significant differences in all covariates after PSM procedures, suggesting that the matched firms closely resemble the insured firms along virtually all dimensions.

Given the absence of clear regulations mandating listed firms to purchase D&O insurance in China and the varied introduction times of D&O insurance by firms, as noted by Beck et al. (2010), we proceed to employ the treatment group and the matched control group to execute a multi-period DID model, formulated as follows:

$$CO2_{i,t}=\alpha+\beta Treat\times Post_{i,t}+\sum Controls+k_i+k_y+k_j+\varepsilon_{i,t} \quad (5)$$

Where $i$ and $t$ refer to the firm and year respectively. *Controls* are the same set of control variables defined in model (1). $k_i$, $k_y$, $k_j$ are firm, year, and industry fixed effect respectively. $\varepsilon_{i,t}$ is the error term. *Treat* is a dummy variable equals 1 for the treatment group, and 0 for the control group. Specially, if a firm starts and continues purchasing D&O insurance, we classify it into the treatment group; if a firm are never insured, we classify it into the control group. *Post* is also a dummy variable that equals 1 since the year a firm starts purchasing D&O insurance, and 0 otherwise. We mainly focus on the coefficient of *Treat*×*Post*, which should be significantly negative if our main results are robust.

The results are reported in Table 8. The coefficient of *Treat*×*Post* is significantly negative at the 1% level (β=-0.075, t=-2.78), so our main results are robust.

**Table 7 Covariate balance test**

| Variable | Unmatched Matched | Mean Treated | Mean Control | %bias | %reduce \|bias\| | t-value | P>\|t\| |
|---|---|---|---|---|---|---|---|
| *Size* | U | 22.230 | 21.870 | 31.2 | | 20.37 | 0.000*** |
| | M | 22.187 | 22.206 | -1.7 | 94.6 | -0.84 | 0.399 |
| *Lev* | U | 0.424 | 0.393 | 15.3 | | 9.59 | 0.000*** |
| | M | 0.421 | 0.423 | -0.6 | 96.0 | -0.31 | 0.755 |
| *ROA* | U | 0.040 | 0.040 | -0.5 | | -0.33 | 0.740 |
| | M | 0.039 | 0.039 | 1.0 | -97.6 | 0.53 | 0.599 |
| *Growth* | U | 0.180 | 0.171 | 2.6 | | 1.61 | 0.107 |
| | M | 0.180 | 0.185 | -1.2 | 53.3 | -0.60 | 0.551 |
| *Cfo* | U | 0.051 | 0.048 | 4.6 | | 2.89 | 0.004*** |
| | M | 0.051 | 0.051 | 0.5 | 88.3 | 0.28 | 0.782 |
| *Epe* | U | 0.030 | 0.024 | 6.5 | | 4.33 | 0.000*** |
| | M | 0.029 | 0.028 | 0.5 | 92.3 | 0.25 | 0.804 |
| *BM* | U | 0.598 | 0.583 | 6.7 | | 4.25 | 0.000*** |
| | M | 0.596 | 0.596 | 0.1 | 98.7 | 0.04 | 0.964 |
| *Director* | U | 8.594 | 8.441 | 9.8 | 98.0 | 6.18 | 0.000*** |
| | M | 8.585 | 8.588 | -0.2 | | -0.10 | 0.922 |
| *Idr* | U | 0.372 | 0.375 | -4.4 | | -2.75 | 0.006*** |
| | M | 0.373 | 0.373 | 0.0 | 99.6 | 0.01 | 0.994 |
| *Dual* | U | 0.277 | 0.317 | -8.7 | | -5.46 | 0.000*** |
| | M | 0.278 | 0.287 | -2.0 | 77.5 | -1.02 | 0.309 |
| *Top1* | U | 32.019 | 33.776 | -5.4 | 97.1 | -3.41 | 0.001*** |
| | M | 32.064 | 33.087 | -0.2 | | -0.08 | 0.937 |
| *Gqz* | U | 0.779 | 0.722 | 9.6 | 85.4 | 6.06 | 0.000*** |
| | M | 0.770 | 0.779 | -1.4 | | -0.69 | 0.493 |

Electronic copy available at: https://ssrn.com/abstract=4630608

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *SOE* | U | 0.376 | 0.271 | 22.7 | 92.8 | 14.67 | 0.000*** |
| | M | 0.369 | 0.376 | -1.6 | | -0.81 | 0.420 |
| *Age* | U | 2.161 | 2.008 | 19.7 | 95.6 | 12.32 | 0.000*** |
| | M | 2.150 | 2.156 | -0.9 | | -0.46 | 0.647 |
| *GDPgrowth* | U | 0.100 | 0.100 | -0.4 | | -0.23 | 0.820 |
| | M | 0.100 | 0.100 | 1.5 | -325.7 | 0.79 | 0.429 |

This table reports the results of covariate balance test of PSM-DID sample. *, **, *** represent statistically significantly different from zero at the 0.10, 0.05, and 0.01 level, respectively.

**Table 8 PSM-DID approaches**

| | PSM-DID |
|---|---|
| | *CO2* |
| *Treat×Post* | -0.075*** |
| | (-2.78) |
| *Size* | -0.004 |
| | (-0.20) |
| *Lev* | 0.272*** |
| | (2.60) |
| *ROA* | -0.942*** |
| | (-7.32) |
| *Growth* | -0.023 |
| | (-1.58) |
| *Cfo* | -0.293*** |
| | (-2.98) |
| *Epe* | -0.391** |
| | (-2.40) |
| *BM* | 0.013 |
| | (0.27) |
| *Director* | 0.014 |
| | (1.30) |
| *Idr* | -0.020 |
| | (-0.11) |
| *Dual* | 0.003 |
| | (0.21) |
| *Top1* | 0.002 |
| | (1.11) |
| *Gqz* | 0.028 |
| | (0.94) |
| *SOE* | -0.020 |
| | (-0.44) |
| *Age* | 0.096*** |
| | (2.82) |
| *GDPgrowth* | 0.312** |
| | (2.07) |
| *Constant* | 0.268 |
| | (0.60) |
| *Firm* | Yes |
| *Year* | Yes |
| *Ind.* | Yes |
| Obs. | 10522 |
| Adj. $R^2$ | 0.301 |

This table reports the results of PSM-DID approach. Reported in parentheses are t-values based on robust standard errors clustered at the firm level. *, **, *** represent statistically significantly different from zero at the 0.10, 0.05,

Electronic copy available at: https://ssrn.com/abstract=4630608

and 0.01 level, respectively.

## 5.7 Controlling for firm fixed effects

To safeguard against potential issues arising from omitted unobservable variables that may remain constant over time and could impact our baseline regression results, we introduce firm fixed effects into Model (1). The outcomes are presented in Table 9. In Column (1), we solely incorporate firm fixed effects, while in Column (2), we extend control to include industry and year fixed effects. The results reveal that the coefficients of D&O insurance (*DOI*) remain consistently negative and statistically significant at the 5% level (β=-0.055, t=-2.08; β=-0.055, t=-2.16) across both specifications. Hence, our findings suggest that the observed effects are less likely attributable to omitted variables that persist over time.

**Table 9 Robustness tests controlling firm fixed effect**

| | (1)<br>*CO2* | (2)<br>*CO2* |
|---|---|---|
| *DOI* | -0.055** | -0.055** |
| | (-2.08) | (-2.16) |
| *Size* | -0.083*** | 0.017 |
| | (-4.64) | (1.10) |
| *Lev* | 0.425*** | 0.173*** |
| | (5.34) | (2.82) |
| *ROA* | -0.952*** | -1.056*** |
| | (-8.26) | (-10.72) |
| *Growth* | -0.026** | -0.036*** |
| | (-2.29) | (-3.61) |
| *Cfo* | -0.033 | -0.251*** |
| | (-0.47) | (-4.00) |
| *Epe* | -0.399*** | -0.301*** |
| | (-3.23) | (-2.74) |
| *BM* | 0.098*** | -0.041 |
| | (3.41) | (-1.14) |
| *Director* | 0.010 | 0.004 |
| | (1.17) | (0.56) |
| *Idr* | -0.140 | -0.095 |
| | (-0.74) | (-0.58) |
| *Dual* | -0.001 | 0.005 |
| | (-0.07) | (0.40) |
| *Top1* | -0.000 | 0.001 |
| | (-0.17) | (1.07) |
| *Gqz* | 0.016 | 0.023 |
| | (0.61) | (1.03) |
| *SOE* | 0.061 | -0.025 |
| | (1.50) | (-0.73) |
| *Age* | -0.036* | 0.054** |
| | (-1.70) | (2.18) |
| *GDPgrowth* | 0.596*** | 0.047 |
| | (5.95) | (0.44) |
| *Constant* | 2.232*** | -0.005 |
| | (5.85) | (-0.02) |
| *Firm* | Yes | Yes |
| *Year* | No | Yes |

Electronic copy available at: https://ssrn.com/abstract=4630608

| | | |
|---|---|---|
| *Ind.* | No | Yes |
| Obs. | 21950 | 21950 |
| Adj. $R^2$ | 0.056 | 0.331 |

This table reports the impact of D&O insurance on carbon emission intensity controlling firm fixed effect. We first control firm fixed effect and report the results in Column (1) and further control year and industry fixed effect and report the results in Column (2). Reported in parentheses are t-values based on robust standard errors clustered at the firm level. *, **, *** represent statistically significantly different from zero at the 0.10, 0.05, and 0.01 level, respectively.

## 5.8 Instrumental variable approach

We employ an instrumental variable approach to address potential endogeneity concerns. Diverging from earlier studies (Lin et al., 2011), which utilize the industry-average D&O insurance incidence as the instrumental variable for a firm's D&O insurance incidence, we opt for the city-year mean value of other firms' D&O insurance incidence as the instrumental variable (*IV*). This choice is motivated by the notion that a firm's decision to acquire D&O insurance might be influenced by other firms operating and competing in the same market, while the purchasing decisions of other firms may not directly impact the firm's carbon emission intensity. The selected *IV* aligns with the prerequisites of an instrumental variable approach.

Table 10 presents the results of the instrumental variable approach. The coefficient of the *IV* is significantly negative at the 1% level (β=-0.062, t=-4.41). The Hausman test rejects the null hypothesis, indicating the suitability of adopting the instrumental variable approach (P=0.012). The Cragg-Donald F statistic is 25061.9, signifying a robust instrument. The Anderson canonical correlation LM statistic is significant at the 1% level (P=0.000), attesting to the identification and validity of the instrumental variable. In summary, the instrumental variable test underscores the robustness of the association between D&O insurance and carbon emission intensity.

**Table 10 Instrumental variable approach**

| | *CO2* |
|---|---|
| *IV* | -0.062*** |
| | (-4.41) |
| *Size* | -0.001 |
| | (-0.30) |
| *Lev* | 0.043** |
| | (2.40) |
| *ROA* | -1.057*** |
| | (-19.03) |
| *Growth* | -0.024*** |
| | (-3.12) |
| *Cfo* | -0.204*** |
| | (-4.59) |
| *Epe* | -0.109*** |
| | (-3.64) |
| *BM* | -0.047*** |
| | (-3.02) |
| *Director* | -0.003 |
| | (-1.56) |
| *Idr* | 0.043 |
| | (0.75) |
| *Dual* | 0.003 |

Electronic copy available at: https://ssrn.com/abstract=4630608

| | |
|---|---|
| | (0.45) |
| *Top1* | 0.001*** |
| | (4.15) |
| *Gqz* | 0.021*** |
| | (3.29) |
| *SOE* | 0.009 |
| | (1.21) |
| *Age* | 0.010** |
| | (2.23) |
| *GDPgrowth* | 0.069 |
| | (0.92) |
| *Constant* | 0.643*** |
| | (8.88) |
| *Year* | Yes |
| *Ind.* | Yes |
| Obs. | 21950 |
| Adj. $R^2$ | 0.808 |
| Hausman test | 0.012 |
| Cragg-Donald Wald F-stat | 25061.9>16.38 |
| Under-identification test | 11715.92***（0.000） |
| Over-identification test | equation exactly identified |

This table reports the results of instrumental variable approach. Reported in parentheses are t-values based on robust standard errors clustered at the firm level. *, **, *** represent statistically significantly different from zero at the 0.10, 0.05, and 0.01 level, respectively.

5.9 Long Horizons

Excessive carbon emissions represent a persistent challenge, and enduring effects on CO2 emissions necessitate a more sustained impact (Belbute & Pereira, 2017). Consequently, if D&O insurance can only furnish a one-shot incentive, its efficacy in maintaining a low level of carbon emission intensity over the long term might be limited.

In this section, we scrutinize whether D&O insurance yields an enduring impact on reducing corporate carbon emission intensity. We substitute the dependent variable $CO2_{i,t}$ in model (1) with $CO2_{i,t+1}$ to $CO2_{i,t+6}$ to assess the influence of D&O insurance in the subsequent 1 to 6 years. The results, as presented in Table 11, reveal that the coefficients of *DOI* are significantly negative in the next 1 to 4 years (β=-0.045, t=-2.70; β=-0.039, t=-2.42; β=-0.031, t=-1.87; β=-0.030, t=-1.75). Thus, the impact of D&O insurance is long-lasting during this period. However, in the subsequent 5 and 6 years, the coefficients of *DOI* are negative but statistically insignificant, suggesting that the effect of D&O insurance is not permanent. In essence, the influence of D&O insurance on carbon emission intensity endures for a considerable duration, indicating its persistent effect.

**Table 11 Long-term effect of D&O insurance on carbon emission intensity**

| | (1) $CO2_{t+1}$ | (2) $CO2_{t+2}$ | (3) $CO2_{t+3}$ | (4) $CO2_{t+4}$ | (5) $CO2_{t+5}$ | (6) $CO2_{t+6}$ |
|---|---|---|---|---|---|---|
| *DOI* | -0.045*** | -0.039** | -0.031* | -0.030* | -0.024 | -0.028 |
| | (-2.70) | (-2.42) | (-1.87) | (-1.75) | (-1.21) | (-1.22) |
| *Size* | -0.009* | -0.006 | -0.003 | -0.007 | -0.004 | -0.001 |
| | (-1.82) | (-1.09) | (-0.53) | (-1.12) | (-0.62) | (-0.12) |
| *Lev* | 0.066** | 0.073*** | 0.067** | 0.075** | 0.058 | 0.042 |

Electronic copy available at: https://ssrn.com/abstract=4630608

| | | | | | | |
|---|---|---|---|---|---|---|
| | (2.49) | (2.81) | (2.48) | (2.33) | (1.45) | (0.84) |
| *ROA* | -0.461*** | -0.350*** | -0.292*** | -0.240** | -0.231* | -0.142 |
| | (-6.30) | (-3.96) | (-3.09) | (-2.12) | (-1.76) | (-0.98) |
| *Growth* | -0.022** | -0.008 | -0.011 | -0.021** | 0.001 | 0.005 |
| | (-2.21) | (-0.61) | (-0.95) | (-2.00) | (0.06) | (0.31) |
| *Cfo* | -0.304*** | -0.276*** | -0.270*** | -0.226*** | -0.287*** | -0.276*** |
| | (-4.72) | (-4.28) | (-3.87) | (-3.02) | (-3.29) | (-2.81) |
| *Epe* | -0.084* | -0.060 | -0.014 | 0.028 | -0.009 | -0.031 |
| | (-1.75) | (-1.22) | (-0.29) | (0.47) | (-0.13) | (-0.37) |
| *BM* | 0.003 | -0.014 | -0.010 | 0.043 | 0.045 | 0.056 |
| | (0.15) | (-0.62) | (-0.42) | (1.60) | (1.38) | (1.52) |
| *Director* | -0.003 | -0.003 | -0.002 | -0.000 | -0.002 | -0.003 |
| | (-1.05) | (-1.05) | (-0.63) | (-0.06) | (-0.39) | (-0.60) |
| *Idr* | 0.036 | 0.035 | 0.068 | 0.131 | 0.072 | 0.059 |
| | (0.41) | (0.44) | (0.91) | (1.43) | (0.70) | (0.50) |
| *Dual* | 0.006 | 0.009 | 0.008 | 0.006 | 0.000 | -0.004 |
| | (0.84) | (1.18) | (1.02) | (0.61) | (0.03) | (-0.34) |
| *Top1* | 0.001* | 0.001 | 0.000 | 0.000 | -0.000 | 0.000 |
| | (1.91) | (1.58) | (0.34) | (0.01) | (-0.06) | (0.23) |
| *Gqz* | 0.020* | 0.015 | 0.005 | 0.003 | 0.004 | 0.004 |
| | (1.78) | (1.42) | (0.44) | (0.25) | (0.23) | (0.23) |
| *SOE* | 0.008 | 0.007 | 0.000 | -0.005 | -0.011 | -0.013 |
| | (0.81) | (0.71) | (0.02) | (-0.39) | (-0.78) | (-0.79) |
| *Age* | 0.020** | 0.017** | 0.015* | 0.021** | 0.022* | 0.024* |
| | (2.45) | (2.03) | (1.85) | (2.19) | (1.91) | (1.75) |
| *GDPgrowth* | 0.052 | -0.064 | 0.053 | 0.200 | 0.200 | 0.213 |
| | (0.54) | (-0.57) | (0.58) | (1.22) | (1.05) | (0.92) |
| *Constant* | 0.746*** | 0.575*** | 0.440*** | 0.170 | 0.186 | 0.106 |
| | (7.65) | (6.11) | (4.44) | (1.55) | (1.47) | (0.75) |
| *Year* | Yes | Yes | Yes | Yes | Yes | Yes |
| *Ind.* | Yes | Yes | Yes | Yes | Yes | Yes |
| Obs. | 18209 | 15653 | 13386 | 11228 | 9434 | 7882 |
| Adj. $R^2$ | 0.799 | 0.795 | 0.802 | 0.819 | 0.794 | 0.778 |

This table reports the long-term effect of D&O insurance on carbon emission intensity. Column (1) to (6) report the effect of D&O insurance in the next one to six years. Reported in parentheses are t-values based on robust standard errors clustered at the firm level. *, **, *** represent statistically significantly different from zero at the 0.10, 0.05, and 0.01 level, respectively.

## 6. Mechanism Analysis

Having assessed the influence of D&O insurance on the carbon emission intensity of manufacturing firms, we proceed to empirically investigate the channels articulated in our hypothesis development. Specifically, we explore the effectiveness of green innovation and internal control as mechanisms, aiming to illuminate the pathways through which D&O insurance impacts carbon emission intensity. Following the framework outlined by Baron & Kenny (1986), we employ the subsequent models for testing the mediation effects:

$$M_{i,t}=\beta_0+\beta_1 DOI_{i,t}+\sum Controls+\sum Year+\sum Ind+\varepsilon_{i,t} \quad (6)$$

$$CO2_{i,t}=\beta_0+\beta_1 DOI_{i,t}+\beta_2 M_{i,t}+\sum Controls+\sum Year+\sum Ind+\varepsilon_{i,t} \quad (7)$$

Electronic copy available at: https://ssrn.com/abstract=4630608

Where *i* and *t* are firm and year respectively. *M* is the mediators including variables measuring green innovation and the variable measuring internal control. *Controls* are the same as those in model (1). We first apply model (6) to test the association of D&O insurance and the mediators, and then apply model (7) to test the mediation effect.

6.1 Mediation effect of green innovation

As elucidated earlier, D&O insurance exhibits the potential to mitigate carbon emission intensity by fostering a firm's engagement in green innovation. Following the methodology outlined by Hu et al. (2021), we employ green patents as a proxy for green innovation. Specifically, green patents (*EnvrPat*) are defined as the natural logarithm of the number of green patent applications submitted by a firm in a given year, incremented by 1.

Distinguishing between two categories of green innovation, as per Liu et al. (2021), we define substantive green innovation (*SubEnvrPat*) as the natural logarithm of the number of green invention patent applications, plus 1, and strategic green innovation (*StrEnvrPat*) as the natural logarithm of the number of green utility model patent applications, plus 1.

Table 12 presents the mediation effect of green innovation. We employ green patent (*EnvrPat*) as the mediator and report the results of model (6) in Column (1) and model (7) in Column (2). Columns (3) and (4) present the results with green invention patent (*SubEnvrPat*) as the mediator, while Columns (5) and (6) report the regression results with green utility model patent (*StrEnvrPat*) as the mediator.

The results indicate that the coefficient of *DOI* in Column (1) is positive and significant at the 1% level (β=0.159, t=3.11), suggesting that D&O insurance positively influences a firm's green innovation. The coefficient of *EnvPat* in Column (2) is negative and significant at the 5% level (β=-0.009, t=-2.57), and Sobel-Goodman test indicates the mediation effect is significant at the 1% level (Z=-2.729, P=0.006). This establishes green innovation as an effective mechanism, confirming Hypothesis 2a.

When comparing substantive green innovation with strategic green innovation, the coefficients of *DOI* in Columns (3) and (5) are both positive and significant at the 1% level (β=0.154, t=3.38; β=0.106, t=2.85), implying that D&O insurance promotes green innovation, regardless of it being substantive or strategic. The coefficient of *SubEnvrPat* in Column (4) is negative and significant at the 1% level (β=-0.012, t=-2.77), while the coefficient of *StrEnvrPat* in Column (6) is negative but insignificant. Sobel-Goodman tests reveal that the mediation effect of substantive green innovation (*SubEnvrPat*) is significant at the 1% level (Z=-3.015, P=0.003), while the mediation effect of strategic green innovation (*StrEnvrPat*) is insignificant. These results indicate that substantive green innovation effectively reduces carbon emission intensity, whereas strategic green innovation does not play an effective mediating role, thereby validating Hypothesis 2b. Furthermore, the coefficients of *DOI* in Columns (2) and (4) remain significantly negative, suggesting that both green innovation and substantive green innovation act as partial mediators.

In summary, our findings in this section affirm that green innovation serves as an effective conduit through which D&O insurance influences corporate carbon emission intensity. Moreover, when contrasting strategic and substantive green innovation, it is evident that substantive green innovation is more effective, aligning with our hypotheses.

**Table 12 The mediation effects of green innovation**

Electronic copy available at: https://ssrn.com/abstract=4630608

| | Green innovation | | Substantive green | | Strategic green | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| | *EnvrPat* | *CO2* | *SubEnvrPat* | *CO2* | *StrEnvrPat* | *CO2* |
| *DOI* | 0.159*** | -0.036*** | 0.154*** | -0.036*** | 0.106*** | -0.037*** |
| | (3.11) | (-2.76) | (3.38) | (-2.74) | (2.85) | (-2.81) |
| *EnvrPat* | | -0.009** | | | | |
| | | (-2.57) | | | | |
| *SubEnvrPat* | | | | -0.012*** | | |
| | | | | (-2.77) | | |
| *StrEnvrPat* | | | | | | -0.007 |
| | | | | | | (-1.40) |
| *Size* | 0.278*** | 0.001 | 0.242*** | 0.001 | 0.185*** | -0.001 |
| | (12.70) | (0.15) | (12.59) | (0.23) | (11.14) | (-0.11) |
| *Lev* | 0.153** | 0.045 | 0.091 | 0.044 | 0.154*** | 0.044 |
| | (2.15) | (1.63) | (1.50) | (1.62) | (2.98) | (1.62) |
| *ROA* | 0.441*** | -1.049*** | 0.369*** | -1.049*** | 0.261** | -1.052*** |
| | (2.90) | (-12.48) | (2.97) | (-12.48) | (2.32) | (-12.50) |
| *Growth* | -0.103*** | -0.025*** | -0.090*** | -0.025*** | -0.062*** | -0.024*** |
| | (-5.85) | (-2.97) | (-6.07) | (-2.99) | (-4.61) | (-2.91) |
| *Cfo* | 0.246** | -0.203*** | 0.103 | -0.204*** | 0.196** | -0.204*** |
| | (1.99) | (-3.48) | (1.00) | (-3.50) | (2.10) | (-3.49) |
| *Epe* | -0.167** | -0.109** | -0.101 | -0.109** | -0.114** | -0.108** |
| | (-2.13) | (-2.28) | (-1.22) | (-2.27) | (-2.19) | (-2.27) |
| *BM* | -0.185*** | -0.048** | -0.230*** | -0.049** | -0.092** | -0.047** |
| | (-2.99) | (-2.13) | (-4.35) | (-2.18) | (-2.02) | (-2.09) |
| *Director* | 0.019 | -0.003 | 0.016 | -0.003 | 0.012 | -0.003 |
| | (1.60) | (-1.04) | (1.55) | (-1.03) | (1.36) | (-1.07) |
| *Idr* | 0.314 | 0.043 | 0.306 | 0.044 | 0.244 | 0.042 |
| | (1.22) | (0.46) | (1.36) | (0.46) | (1.25) | (0.44) |
| *Dual* | 0.056** | 0.003 | 0.051** | 0.003 | 0.024 | 0.003 |
| | (2.24) | (0.44) | (2.44) | (0.46) | (1.26) | (0.39) |
| *Top1* | -0.005*** | 0.001** | -0.004*** | 0.001** | -0.003*** | 0.001** |
| | (-3.66) | (2.39) | (-3.42) | (2.39) | (-3.07) | (2.44) |
| *Gqz* | -0.084*** | 0.020* | -0.056** | 0.020* | -0.056*** | 0.020* |
| | (-3.14) | (1.80) | (-2.44) | (1.81) | (-2.83) | (1.83) |
| *SOE* | 0.088** | 0.009 | 0.099*** | 0.009 | 0.025 | 0.008 |
| | (2.43) | (0.85) | (3.17) | (0.88) | (0.94) | (0.78) |
| *Age* | -0.166*** | 0.008 | -0.125*** | 0.008 | -0.116*** | 0.009 |
| | (-9.19) | (1.05) | (-8.40) | (1.05) | (-8.40) | (1.15) |
| *GDPgrowth* | 0.219 | 0.070 | 0.129 | 0.070 | 0.179 | 0.070 |
| | (1.01) | (0.69) | (0.72) | (0.68) | (1.16) | (0.68) |
| *Constant* | -5.639*** | 0.610*** | -4.972*** | 0.601*** | -3.810*** | 0.637*** |
| | (-12.30) | (6.17) | (-11.99) | (5.98) | (-11.11) | (6.51) |
| *Year* | Yes | Yes | Yes | Yes | Yes | Yes |
| *Ind.* | Yes | Yes | Yes | Yes | Yes | Yes |
| Obs. | 21950 | 21950 | 21950 | 21950 | 21950 | 21950 |
| Adj. $R^2$ | 0.208 | 0.809 | 0.192 | 0.809 | 0.184 | 0.808 |
| Sobel- | Z=-2.729, P=0.006*** | | Z=-3.015, P=0.003*** | | Z=-1.579, P=0.114 | |

This table reports the results of mediation effects of green innovation. Column (1) and Column (2) present the regression results with green innovation as the mediator. Column (3) and Column (4) present the regression results with substantive green innovation as the mediator. Column (5) and Column (6) present the regression results with strategic green innovation as the mediator. Reported in parentheses are t-values based on robust standard errors clustered at the firm level. *, **, *** represent statistically significantly different from zero at the 0.10, 0.05, and

Electronic copy available at: https://ssrn.com/abstract=4630608

0.01 level, respectively.

6.2 Mediation effect of internal control

In the preceding section, we posited that the impact of D&O insurance on carbon emission intensity operates through the enhancement of corporate internal control. Drawing on established literature (Qi et al., 2017; Qussii & Boulila Taktak, 2018), we employ a dummy variable, denoted as *IC*, as a proxy for internal control. Specifically, *IC* takes the value of 1 if a firm receives a standard opinion internal control audit report or if the evaluation of internal control is deemed effective without deficiencies in a given year; otherwise, it assumes the value of 0.

To assess the influence of D&O insurance (*DOI*) on internal control (*IC*), we employ model (6) and conduct a probit regression, with the results presented in Column (1) of Table 13. Subsequently, we utilize model (7) to explore the mediation effect of *IC* and report the outcomes in Column (2) of Table 13.

In Column (1), the coefficient of *DOI* is significantly positive at the 5% level (β=0.164, t=2.09), indicating that D&O insurance positively impacts a firm's internal control quality. Moving to Column (2), the coefficient of *IC* is significantly negative at the 1% level (β=-0.049, t=-3.10), and the Sobel-Goodman test indicates that the mediation effect is significant at the 1% level (Z=-3.664, P=0.000). This signifies that an effective internal control mechanism contributes to the reduction of carbon emission intensity, establishing internal control as an effective mechanism. Furthermore, the coefficient of *DOI* in Column (2) is significantly negative, confirming that internal control quality acts as a partial mediator. Thus, Hypothesis 3 is substantiated.

**Table 13 The mediation effects of internal control**

| | (1)<br>*IC* | (2)<br>*CO2* |
|---|---|---|
| *DOI* | 0.164** | -0.036*** |
| | (2.09) | (-2.71) |
| *IC* | | -0.049*** |
| | | (-3.10) |
| *Size* | 0.016 | -0.002 |
| | (0.57) | (-0.30) |
| *Lev* | -0.318** | 0.039 |
| | (-2.56) | (1.40) |
| *ROA* | 2.065*** | -1.030*** |
| | (7.43) | (-12.25) |
| *Growth* | -0.034 | -0.024*** |
| | (-0.97) | (-2.90) |
| *Cfo* | 0.369 | -0.201*** |
| | (1.62) | (-3.48) |
| *Epe* | 0.027 | -0.107** |
| | (0.13) | (-2.26) |
| *BM* | 0.096 | -0.045** |
| | (0.92) | (-1.98) |
| *Director* | -0.013 | -0.004 |
| | (-0.88) | (-1.15) |
| *Idr* | 0.001 | 0.040 |
| | (0.00) | (0.42) |
| *Dual* | 0.114*** | 0.004 |

Electronic copy available at: https://ssrn.com/abstract=4630608

| | | |
|---|---|---|
| | (2.87) | (0.52) |
| *Top1* | -0.000 | 0.001** |
| | (-0.18) | (2.48) |
| *Gqz* | -0.014 | 0.020* |
| | (-0.31) | (1.87) |
| *SOE* | 0.033 | 0.008 |
| | (0.64) | (0.77) |
| *Age* | -0.434*** | 0.005 |
| | (-11.55) | (0.69) |
| *GDPgrowth* | -0.406 | 0.063 |
| | (-1.06) | (0.61) |
| *Constant* | 0.387*** | 0.644*** |
| | (2.63) | (6.76) |
| *Year* | Yes | Yes |
| *Ind.* | Yes | Yes |
| Obs. | 21950 | 21950 |
| Adj. $R^2$ | 0.139 | 0.809 |
| Pseudo $R^2$ | 0.145 | |
| Sobel-Goodman | Z=-3.664, P=0.000*** | |

This table reports the results of mediation effects of internal control. Reported in parentheses are t-values based on robust standard errors clustered at the firm level. *, **, *** represent statistically significantly different from zero at the 0.10, 0.05, and 0.01 level, respectively.

## 7. Heterogeneity Analysis

In this section, we delve into potential heterogeneity by considering variations at the provincial and city levels, taking into account regional environmental regulations and resource endowments. Additionally, we scrutinize firm-level distinctions, such as executive compensation structures and the separation of ownership and control.

7.1 Heterogeneous effects from the perspective of regional environmental regulation

Previous research has convincingly demonstrated that regional environmental regulations wield considerable influence as external forces shaping the environmental practices of enterprises. The Porter hypothesis (Porter, 1991; Porter & van der Linde, 1995) posits that appropriately structured environmental regulations can trigger an "innovation compensation effect," fostering innovation in green technologies and driving sustainable development. Consequently, the inclination of local governments becomes pivotal. Studies by Sun et al. (2020), Cai et al. (2020), and Zhang et al. (2023) underscore the substantial impact of government initiatives on corporate behaviors, highlighting correlations between pollution treatment investments, R&D expenditures, green patents, and overall environmental responsibilities.

Consistent with established literature (Zhang & Li, 2020), we employ the Environmental Pollution Investment-to-GDP ratio (*EPI*) as a proxy for regional environmental regulation. A higher *EPI* signifies more stringent environmental regulation. We match the *EPI* values to our sample firms based on their registration provinces and categorize observations into high *EPI* and low *EPI* groups according to the annual averages of *EPI*. The results of grouped tests are presented in Columns (1) and (2) of Table 14.

In Table 14, Column (1) provides the regression outcomes for the high *EPI* group, while Column (2) presents the results for the low *EPI* group. The coefficients of *DOI* are significantly negative at the 10% and 5% levels (β=-0.039, t=-1.83; β=-0.038, t=-2.39). Fisher's Permutation test, yielding an empirical P value of 0.001, affirms the

Electronic copy available at: https://ssrn.com/abstract=4630608

significance difference at the 1% level, with the coefficient of *DOI* in the low *EPI* group exhibiting greater significance.

Overall, our findings reveal heterogeneity in the relationship between D&O insurance and carbon emission intensity concerning regional environmental regulation, with a more pronounced association observed in firms operating within regions characterized by lax environmental regulations. This divergence could be attributed to firms in regions with stringent environmental regulations facing external pressures to reduce carbon emissions, thus limiting the additional incentive provided by D&O insurance. In contrast, firms in regions with less stringent regulations might find the impact of D&O insurance on carbon emission reduction more pronounced due to a lack of external pressures to curb emissions.

7.2 Heterogeneous effects from the perspective of regional resource endowment

The resource endowment of a city exerts a substantial influence on the predominant industries operating within that region. For instance, Daqing city serves as a crucial hub for China's oil production and petrochemical industry. Consequently, manufacturing firms in this region predominantly engage in oil and petrochemical activities, inherently resulting in elevated carbon emissions. For such enterprises, the efficacy of D&O insurance in reducing carbon emission intensity is constrained by the nature of their primary operations. Therefore, regional resource endowment emerges as a pivotal external factor shaping a firm's core business activities and, consequently, its capacity to curtail carbon emissions.

To gauge regional resource endowment, we follow the methodology of Yang et al. (2019) and categorize cities into resource-based and non-resource-based cities, adhering to the National Sustainable Development Plan of Resource-Based Cities (2013-2020) outlined by the State Council in China. As per this plan, a resource-based city is characterized by dominance in the extraction and processing of natural resources such as minerals and forests within its vicinity, encompassing a total of 262 resource-based cities. We employ a binary variable (*RB*), taking a value of 1 if the firm is registered in a resource-based city and 0 otherwise.

Columns (3) and (4) of Table 14 present the outcomes of the heterogeneity analysis concerning regional resource endowment. Column (3) outlines results for firms in resource-based cities, while Column (4) delineates results for firms in non-resource-based cities. The coefficient of *DOI* for firms in non-resource-based cities is significantly negative at the 1% level ($\beta$=-0.033, t=-2.63), while the corresponding coefficient for firms in resource-based cities does not attain statistical significance. Fisher's Permutation test reveals an empirical P value of 0.011, confirming the significant difference in coefficients at the 5% level, with the coefficient of *DOI* in the non-resource-based group exhibiting greater significance.

In summary, our findings underscore heterogeneity in the context of regional resource endowment. The association between D&O insurance and carbon emission intensity is more pronounced for firms situated in non-resource-based cities. These results affirm our hypothesis, suggesting that firms in resource-based cities face greater challenges in mitigating carbon emissions due to their reliance on high carbon dioxide-intensive industries, while firms in non-resource-based cities are more amenable to reducing carbon emissions incentivized by D&O insurance.

7.3 Heterogeneous effects from the perspective of executive compensation

Compensation incentive theory posits that a judiciously structured salary serves as a motivational tool for executives to conscientiously fulfill their professional responsibilities and make sound business decisions. Robust compensation incentives empower executives to undertake their duties with diligence, engaging in valuable

Electronic copy available at: https://ssrn.com/abstract=4630608

projects that contribute to corporate value creation (Guay, 1999; Coles et al., 2006; Chen & Ma, 2011). Given the escalating emphasis on carbon reduction both at the policy and organizational levels, an elevated salary may act as a catalyst, inspiring executives to align with environmental imperatives and bolster green initiatives, ultimately fostering carbon emission reduction.

Consistent with prior studies (Chizema et al., 2015; Lyu et al., 2023), we operationalize executive compensation (*Pay*) by employing the average salary of the top three executives. Subsequently, we categorize observations based on the annual average *Pay* into two groups: those exceeding the annual average value and those falling below it.

Table 14 presents the outcomes of our analysis. Column (5) furnishes the results for the high *Pay* group, while Column (6) outlines findings for the low *Pay* group. The coefficient of *DOI* in the low executive compensation group attains statistical significance at the 5% level (β=-0.038, t=-2.35), contrasting with the non-significant coefficient in the high executive compensation group. Fisher's Permutation test yields an empirical P value of 0.005, confirming the significant disparity in coefficients at the 1% level, with the coefficient of *DOI* in the low *Pay* group exhibiting greater significance.

Hence, there exists heterogeneity in the context of executive compensation. The relationship between D&O insurance and carbon emission intensity is more pronounced in firms characterized by lower executive compensation. Plausibly, lower compensation fails to adequately offset the additional risks borne by executives committed to green development, thereby dampening their motivation to reduce carbon emissions. D&O insurance, by mitigating these additional risks, acts as a catalyst, encouraging executives to intensify their green initiatives. However, the impact of D&O insurance on carbon emission reduction is attenuated in the presence of higher executive compensation. Consequently, the association between D&O insurance and carbon emission reduction manifests as significantly more pronounced in the low executive compensation group.

7.4 Heterogeneous effects from the perspective of separation of ownership and control

Drawing on the principles of agency theory, the separation of ownership and control gives rise to agency problems (Jensen & Meckling, 1976; Badertscher et al., 2013). Unlike shareholders who can diversify risk through investment portfolios, managers' interests are often intricately linked to a single company (Sharpe, 1964), leading to potential self-interested behaviors by management. To safeguard their interests, management may be disinclined to assume additional risks to promote energy conservation and emission reduction. D&O insurance serves as a mitigating factor for the agency problem (Priest, 1987; Hoyt & Khang, 2000), thereby encouraging management to prioritize green development. Consequently, we investigate whether the separation of ownership and control contributes to heterogeneity in the association between D&O insurance and carbon emission reduction.

Following Maury (2006), we utilize the difference between control rights and cash-flow rights held by the largest shareholder (*Separation*) as a metric to measure ownership and control separation. We further segment our sample based on the annual average of *Separation* into high *Separation* and low *Separation* groups. The outcomes of the group tests are presented in Column (7) and (8) of Table 14.

In Column (7), we present the regression results for the high *Separation* group, revealing a significantly negative coefficient of *DOI* at the 1% level (β=-0.086, t=-3.39). Conversely, the coefficient of *DOI* in the low *Separation* group fails to reach

Electronic copy available at: https://ssrn.com/abstract=4630608

statistical significance. Fisher's Permutation test underscores the significance of the empirical P value at 0.099, confirming that the coefficients exhibit significant differences at the 10% level, with the coefficient of *DOI* in the high Separation group displaying greater significance.

Consequently, heterogeneity emerges in the relationship between D&O insurance and carbon emission reduction concerning the separation of ownership and control. The reduction effect of D&O insurance on carbon emission intensity is more pronounced in the high *Separation* group. This aligns with our conjecture that firms characterized by high separation of ownership and control encounter more acute agency problems, thereby diverting management's focus away from green development. Under such circumstances, D&O insurance proves more instrumental. Conversely, firms with low *Separation* are less susceptible to the impact of agency problems, leading to a weakened effect of D&O insurance.

**Table 14 Heterogeneity analysis tests**

| | Environmental regulation | | Resource endowment | | Executive compensation | | Separation of ownership and control | |
|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| | High | Low | RB | Non RB | High | Low | High | Low |
| | *CO2* | *CO2* | *CO2* | *CO2* | *CO2* | *CO2* | *CO2* | *CO2* |
| *DOI* | -0.039* | -0.038** | -0.082 | -0.033*** | -0.025 | -0.038** | -0.086*** | -0.013 |
| | (-1.83) | (-2.39) | (-0.99) | (-2.63) | (-1.23) | (-2.35) | (-3.39) | (-0.74) |
| *Size* | -0.008 | 0.002 | 0.019 | -0.005 | 0.004 | -0.001 | -0.008 | -0.000 |
| | (-1.02) | (0.31) | (0.90) | (-0.94) | (0.51) | (-0.16) | (-0.87) | (-0.02) |
| *Lev* | 0.000 | 0.073** | -0.128 | 0.069*** | 0.135* | -0.004 | 0.126** | 0.009 |
| | (0.01) | (2.40) | (-1.31) | (2.59) | (3.40) | (-0.13) | (2.54) | (0.28) |
| *ROA* | - | -1.049*** | - | -0.986*** | - | -1.094*** | -1.175*** | -0.985*** |
| | (-7.59) | (-10.55) | (-4.86) | (-11.56) | (-6.15) | (-10.50) | (-6.56) | (-10.10) |
| *Growth* | - | -0.015 | - | -0.011 | - | -0.019* | -0.026** | -0.023** |
| | (-2.98) | (-1.33) | (-3.73) | (-1.35) | (-2.72) | (-1.89) | (-2.07) | (-2.20) |
| *Cfo* | - | -0.139** | - | -0.138** | - | -0.202*** | -0.240** | -0.186*** |
| | (-2.91) | (-2.06) | (-2.23) | (-2.43) | (-2.19) | (-2.79) | (-2.25) | (-2.61) |
| *Epe* | -0.092 | -0.127** | -0.091 | -0.108** | -0.122 | -0.089* | -0.224** | -0.055 |
| | (-1.43) | (-2.36) | (-0.50) | (-2.48) | (-1.58) | (-1.69) | (-2.07) | (-1.10) |
| *BM* | -0.067* | -0.029 | - | -0.034 | - | -0.033 | -0.067* | -0.029 |
| | (-1.92) | (-1.11) | (-1.66) | (-1.54) | (-1.97) | (-1.16) | (-1.65) | (-1.13) |
| *Director* | 0.003 | -0.009** | -0.002 | -0.003 | - | -0.002 | -0.002 | -0.004 |
| | (0.50) | (-2.57) | (-0.18) | (-1.08) | (-1.82) | (-0.44) | (-0.37) | (-1.10) |
| *Idr* | 0.008 | -0.010 | 0.060 | 0.030 | -0.072 | 0.074 | -0.129 | 0.101 |
| | (0.05) | (-0.09) | (0.16) | (0.31) | (-0.64) | (0.55) | (-0.89) | (0.87) |
| *Dual* | 0.020* | -0.006 | -0.012 | 0.004 | - | 0.015 | -0.002 | 0.007 |
| | (1.65) | (-0.64) | (-0.29) | (0.64) | (-1.86) | (1.57) | (-0.11) | (0.80) |
| *Top1* | 0.000 | 0.002*** | 0.001 | 0.001** | 0.001* | 0.001 | 0.001* | 0.001 |
| | (0.34) | (2.84) | (0.81) | (2.20) | (1.96) | (1.62) | (1.80) | (1.57) |
| *Gqz* | 0.002 | 0.030** | 0.047 | 0.016 | 0.035 | 0.018 | 0.009 | 0.024* |
| | (0.14) | (2.11) | (1.19) | (1.47) | (1.64) | (1.39) | (0.50) | (1.89) |
| *SOE* | -0.011 | 0.018 | -0.031 | 0.017* | 0.000 | 0.014 | -0.021 | 0.022* |
| | (-0.65) | (1.35) | (-0.83) | (1.72) | (0.01) | (0.99) | (-1.07) | (1.72) |
| *Age* | 0.020 | 0.003 | 0.051 | 0.003 | -0.005 | 0.019* | -0.010 | 0.018* |
| | (1.49) | (0.34) | (1.42) | (0.40) | (-0.44) | (1.92) | (-0.69) | (1.86) |
| *GDPgrowth* | -0.108 | 0.115 | -0.299 | 0.140 | 0.379* | -0.095 | 0.139 | 0.051 |
| | (-0.98) | (0.62) | (-1.36) | (1.26) | (1.89) | (-0.83) | (0.75) | (0.39) |
| *Constant* | 0.949*** | 0.561*** | 0.613* | 0.656*** | 0.499* | 0.668*** | 0.888*** | 0.575*** |
| | (5.70) | (4.62) | (1.79) | (6.83) | (3.82) | (4.65) | (4.89) | (4.95) |

Electronic copy available at: https://ssrn.com/abstract=4630608

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Year* | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| *Ind.* | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Obs. | 9018 | 12932 | 2790 | 19160 | 7333 | 14617 | 6855 | 15095 |
| Adj. $R^2$ | 0.819 | 0.803 | 0.773 | 0.814 | 0.792 | 0.817 | 0.786 | 0.820 |
| Empirical P | 0.001*** | | 0.011** | | 0.005*** | | 0.099* | |

This table reports the results of heterogeneity analysis. Column (1) and (2) show the heterogeneous effects from the perspective of environmental regulation. Column (3) and (4) show the heterogeneous effects from the perspective of resource endowment. Column (5) and (6) show the heterogeneous effects from the perspective of executive compensation. Column (7) and (8) show the heterogeneous effects from the perspective of separation of ownership and control. We use Fisher's Permutation test for the coefficient difference testing, and conduct self sampling for 1000 times to obtain the corresponding empirical P value through the Bootstrap method. Reported in parentheses are t-values based on robust standard errors clustered at the firm level. *, **, *** represent statistically significantly different from zero at the 0.10, 0.05, and 0.01 level, respectively.

## 8. Discussion

This research delves into the repercussions of corporate adoption of D&O insurance on carbon emissions within the manufacturing sector. The results underscore that the procurement of D&O insurance significantly diminishes carbon emission intensity in enterprises, and this impact endures over time. D&O insurance achieves this reduction by fostering green innovation endeavors within the firm, particularly substantive green innovations, and by fortifying internal control mechanisms. The study scrutinizes the contextual boundaries in which D&O insurance operates, considering both regional and firm-specific dimensions. It is discerned that in regions characterized by lax legal regulations and suboptimal resource endowments, the efficacy of D&O insurance in curbing carbon emissions is more pronounced. Similarly, within organizations featuring lower executive compensation and a heightened separation between ownership and control, the influence of D&O insurance on carbon emission reduction becomes more conspicuous.

### 8.1 Theoretical contributions

To commence, this article extends the inquiry into factors influencing the reduction of corporate carbon emissions. It undertakes empirical verification, marking the inaugural examination, of the efficacy of firms procuring D&O insurance in mitigating carbon emissions. Prevailing research has predominantly concentrated on the macro-level impact of policy regulations and government market interventions on the reduction of corporate carbon emissions (Zhao et al., 2020; Peng et al., 2022; Xu et al., 2023). However, there is a paucity of exploration at the micro-level regarding behavioral incentives that effectively stimulate companies to curtail carbon emissions. While certain studies have scrutinized the influence of factors such as corporate green innovation behavior (Xu et al., 2021), corporate values (Choi & Luo, 2021), and cash holdings on carbon emissions (Gao & Gao, 2023), the analysis of the reduction effect of D&O insurance on corporate carbon emissions from an insurance perspective has yet to be addressed. This study, grounded in the motivational and supervisory effects of D&O insurance, empirically substantiates its role in reducing corporate carbon emissions, thereby contributing additional theoretical support for effective carbon emission reduction. Secondly, this research augments the literature on economic consequences associated with D&O insurance. Existing studies present divergent perspectives on the outcomes of D&O insurance. Affirmative viewpoints posit that

Electronic copy available at: https://ssrn.com/abstract=4630608

D&O insurance yields advantageous effects for firms, such as mitigating corporate risks (Lin et al., 2019), fostering innovation (Lin et al., 2021), and reducing financial restatements (Lin et al., 2013). Conversely, negative viewpoints suggest that D&O insurance unduly shields executives, amplifying agency costs and detrimentally affecting firms (Wang et al., 2016). However, the impact of D&O insurance on corporate carbon emissions remains unexplored in the current literature. Given the relatively brief introduction period and limited prevalence of D&O insurance in the Chinese context, this study leverages favorable data conditions to affirm, from a carbon emission perspective, the positive environmental impact of D&O insurance. Thirdly, this research delves into the mechanisms and boundary conditions of D&O insurance in reducing corporate carbon emissions, furnishing theoretical support and empirical evidence for a comprehensive understanding of the environmental effects of D&O insurance.

### 8.2 Practical implications

The primary findings of this study provide a novel perspective on the efficacious mitigation of corporate carbon emissions, thereby contributing to the global endeavor to reach carbon peaking and achieve neutrality. The research enhances the avenues through which corporations can actively curtail carbon emissions from an insurance standpoint, fostering collaborative initiatives to preserve environmental conditions vital for human survival. Secondly, the study's outcomes furnish favorable evidence supporting the expanded adoption of D&O insurance in China and other developing nations. While the utilization of D&O insurance is well-established in developed Western economies, its implementation remains in its early stages in China and similar contexts. Both governmental and corporate comprehension of the role of D&O insurance is still evolving. The study affirms that D&O insurance manifests positive environmental effects, particularly in regions characterized by less stringent legal regulations. This bears significant implications for developing nations grappling with the absence of robust and comprehensive regulatory frameworks. Thirdly, this study provides a trajectory for developing countries to liberalize their financial markets and partake in international exchanges within the financial sector. Originating from well-established legal frameworks in developed Western nations, D&O insurance has undergone over half a century of evolution, effectively safeguarding executives' performance and galvanizing their proactive involvement. Developing countries have encountered D&O insurance at a later stage, encountering challenges related to underwriting capabilities and the provision of professional services. The study's conclusions yield insights aimed at fortifying international financial exchanges.

### 8.3 Limitations

Currently, the voluntary disclosure of D&O insurance procurement information by Chinese listed companies is a prevailing practice. Throughout this study, the data compilation process is restricted to acquiring basic information on whether a listed company has obtained liability insurance. Detailed particulars, including premiums and coverage extents for D&O insurance, remain inaccessible. Consequently, this research is confined to an examination of the economic implications of D&O insurance through the use of dummy variables, precluding an exploration of how variations in premiums and coverage extents may impact corporate innovation. As corporate information disclosure evolves towards increased transparency, this constraint may be mitigated in future research initiatives.

## References:

Electronic copy available at: https://ssrn.com/abstract=4630608

Aguir, I., & Aguir, W. (2020). Director and officer liability protection and firm value: Unintended consequences. Finance Research Letters, 32, 101177.

Akerlof, G.A. (1970). The market for “Lemons”: Quality uncertainty and the market mechanism. The Quarterly Journal of Economics, 84(3), 488-500.

Alchian, A.A., & Demsetz, H. (1972). Production, information costs, and economic organization. The American Economic Review, 62(5), 777-795.

Ashbaugh-Skaife, H., Collins, D.W., Kinney, J., William, R., & Lafond, R. (2009). The effect of SOX internal control deficiencies on firm risk and cost of equity. Journal of Accounting Research, 47(1), 1-43.

Badertscher, B.A., Katz, S.P., & Rego, S.O. (2013). The separation of ownership and control and corporate tax avoidance. Journal of Accounting and Economics, 56(2-3), 228-250.

Baker, T., & Griffith, S. J. (2019). Ensuring corporate misconduct: How liability insurance undermines shareholder litigation. University of Chicago Press.

Balcombe, P., Brierley, J., Lewis, C., Skatvedt, L., Speirs, J., Hawkes, A., & Staffell, I. (2019). How to decarbonise international shipping: Options for fuels, technologies and policies. Energy conversion and management, 182, 72-88.

Baron, R.M., & Kenny, D.A. (1986). The moderator-mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. Journal of Personality and Social Psychology, 51(6), 1173-1182.

Beck, T., Levine, R., & Levkov, A. (2010). Big bad banks? The winners and losers from bank deregulation in the United States. The Journal of Finance, 65(5), 1637-1667.

Belbute, J.M., & Pereira, A.M. (2017). Do global CO2 emissions from fossil-fuel consumption exhibit long memory? A fractional-integration analysis. Applied Economics, 49(40), 4055-4070.

Boubakri, N., & Bouslimi, L. (2016). Directors’ and officers’ liability insurance and analyst forecast properties. Finance Research Letters, 19, 22-32.

Boyer, M. M., & Stern, L. H. (2014). D&O insurance and IPO performance: What can we learn from insurers?. Journal of Financial Intermediation, 23(4), 504-540.

Cao, Z., & Narayanamoorthy, G. S. (2014). Accounting and litigation risk: Evidence from directors’ and officers’ insurance pricing. Review of Accounting Studies, 19, 1-42.

Chalmers, J. M., Dann, L. Y., & Harford, J. (2002). Managerial opportunism? Evidence from directors' and officers' insurance purchases. The Journal of Finance, 57(2), 609-636.

Chen, L. (2016). Research on managerial power, internal control and corporate environmental disclosure. Ecological Economics, 32(8), 90-95+102.

Chen, Q., Ning, B., Pan, Y., & Xiao, J. (2021). Green finance and outward foreign direct investment: evidence from a quasi-natural experiment of green insurance in China. Asia Pacific Journal of Management, 1-26.

Electronic copy available at: https://ssrn.com/abstract=4630608

Chen, Y.R., & Ma, Y.L. (2011) Revisiting the risk taking effect of executive stock options on firm performance. Journal of Business Research, 64(4), 640-648.

Chen, Z., Li, O. Z., & Zou, H. (2016). Directors′ and officers′ liability insurance and the cost of equity. Journal of Accounting and Economics, 61(1), 100-120.

Cheng, Y., & Yao, X. (2021). Carbon intensity reduction assessment of renewable energy technology innovation in China: A panel data model with cross-section dependence and slope heterogeneity. Renewable and Sustainable Energy Reviews, 135, 110157.

Chizema, A., Liu, X., Lu, J., & Gao, L. (2015). Politically connected boards and top executive pay in Chinese listed firms. Strategic Management Journal, 36(6), 890-906.

Choi, B., & Luo, L. (2021). Does the market value greenhouse gas emissions? Evidence from multi-country firm data. The British Accounting Review, 53(1), 100909.

Chung, H. H., & Wynn, J. P. (2008). Managerial legal liability coverage and earnings conservatism. Journal of Accounting and Economics, 46(1), 135-153.

Coles, J.L., Daniel, N.D. & Naveen, L. (2006) Managerial incentives and risk taking. Journal of Financial Economics, 79(2), 431-468.

Dechezleprêtre, A., & Sato, M. (2017). The impacts of environmental regulations on competitiveness. Review of environmental economics and policy.

Donelson, D. C., Hopkins, J. J., & Yust, C. G. (2018). The cost of disclosure regulation: Evidence from D&O insurance and nonmeritorious securities litigation. Review of Accounting Studies, 23, 528-588.

Erdogan, S. (2021). Dynamic Nexus between technological innovation and building sector carbon emissions in the BRICS countries. Journal Environmental Management, 293, 112780.

Flannery, B. L., & May, D. R. (1994). Prominent factors influencing environmental activities: Application of the environmental leadership model (ELM). The Leadership Quarterly, 5(3-4), 201-221.

Gao, Y., & Gao, J. (2023). Low-carbon transformation and corporate cash holdings. Finance Research Letters, 54, 103842.

Ge, T., Cai, X., & Song, X. (2022). How does renewable energy technology innovation affect the upgrading of industrial structure? The moderating effect of green finance. Renewable Energy, 197, 1106-1114.

Guay, W.R. (1999) The sensitivity of CEO wealth to equity risk: An analysis of the magnitude and determinants. Journal of Financial Economics, 53(1), 43-71.

Habib, A., Hasan, M. M., & Jiang, H. (2018). Stock price crash risk: review of the empirical literature. Accounting & Finance, 58, 211-251.

Hambrick, D.C. (2007). Upper echelons theory: An update. Academy of Management Review, 32(2), 334-343.

Hartzell, J.C., & Starks, L.T. (2003). Institutional investors and executive

Electronic copy available at: https://ssrn.com/abstract=4630608

compensation. The Journal of Finance, 58(6), 2351-2374.

Hickey, C., Deane, P., McInerney, C., & Gallachóir, B. Ó. (2019). Is there a future for the gas network in a low carbon energy system?. Energy Policy, 126, 480-493.

Hoyt, R.E., & Khang, H. (2000). On the demand for corporate property insurance. Journal of Risk and Insurance, 67(1), 91-107.

Hu, G., Wang, X., & Wang, Y. (2021). Can the green credit policy stimulate green innovation in heavily polluting enterprises? Evidence from a quasi-natural experiment in China. Energy Economics, 98, 105134.

Huo, W., Qi, J., Yang, T., Liu, J., Liu, M., & Zhou, Z. (2022). Effects of China's pilot low-carbon city policy on carbon emission reduction: a quasi-natural experiment based on satellite data. Technological Forecasting and Social Change, 175, 121422.

Hwang, J.H., & Kim, B. (2018). Directors' and officers' liability insurance and firm value. Journal of Risk and Insurance, 85(2), 447-482.

Jensen, M. (1993). The modern industrial revolution, exist and the failure of internal control systems. The Journal of Finance, 48(3), 831-880.

Ji, G., Gunasekaran, A., & Yang, G. (2014). Constructing sustainable supply chain under double environmental medium regulations. International Journal of Production Economics, 147, 211-219.

Jiang, M. P., & Tovey, K. (2010). Overcoming barriers to implementation of carbon reduction strategies in large commercial buildings in China. Building and Environment, 45(4), 856-864.

Jiang, S., Li, Y., Lu, Q., Hong, Y., Guan, D., Xiong, Y., & Wang, S. (2021). Policy assessments for the carbon emission flows and sustainability of Bitcoin blockchain operation in China. Nature communications, 12(1), 1-10.

Kanashiro, P., & Rivera, J. (2019). Do chief sustainability officers make companies greener? The moderating role of regulatory pressures. Journal of Business Ethics, 155, 687-701.

Kou, G., Yüksel, S., & Dinçer, H. (2022). Inventive problem-solving map of innovative carbon emission strategies for solar energy-based transportation investment projects. Applied Energy, 311, 118680.

Lee, C.C., Chang, Y.F., & Wang, E.Z. (2022). Crossing the rivers by feeling the stones: The effect of China's green credit policy on manufacturing firms' carbon emission intensity. Energy Economics, 116, 106413.

Leuz, C., Triantis, A., & Wang, T.Y. (2008). Why do firms go dark? Causes and economic consequences of voluntary SEC deregistrations. Journal of Accounting and Economics, 45(2-3), 181-208.

Li, K. F., & Liao, Y. P. (2014). Directors' and officers' liability insurance and investment efficiency: Evidence from Taiwan. Pacific-Basin Finance Journal, 29, 18-34.

Electronic copy available at: https://ssrn.com/abstract=4630608

Li, K. F., & Liao, Y. P. (2021). The Quest for Talented Independent Directors: The Role of Directors' and Officers' Liability Insurance. Journal of Accounting Review, 73.

Li, T., Yang, T., & Zhu, J. (2022). Directors' and officers' liability insurance: evidence from independent directors' voting. Journal of Banking and Finance, 138, 106425.

Li, Z., & Wang, J. (2022). Spatial spillover effect of carbon emission trading on carbon emission reduction: Empirical data from pilot regions in China. Energy, 251, 123906.

Li, Z., Chen, Y., & Li, Y. (2023). Top management abnormal turnover and stock price crash risk: Evidence from China. International Review of Financial Analysis, 89, 102817.

Li, Z., Dai, H., Sun, L., Xie, Y., Liu, Z., Wang, P., & Yabar, H. (2018). Exploring the impacts of regional unbalanced carbon tax on CO2 emissions and industrial competitiveness in Liaoning province of China. Energy Policy, 113, 9-19.

Lian, G., Xu, A., & Zhu, Y. (2022). Substantive green innovation or symbolic green innovation? The impact of ER on enterprise green innovation based on the dual moderating effects. Journal of Innovation and Knowledge, 7(3), 100203.

Liao, T., Lin, B., Liu, J., & Lu, R. (2023). Environmental risk exposure and executive pay-for-performance sensitivity☆. Pacific-Basin Finance Journal, 102200.

Lin, C., Liu, S., & Manso, G. (2021). Shareholder litigation and corporate innovation. Management Science, 67(6), 3346-3367.

Lin, C., Officer, M. S., & Zou, H. (2011). Directors' and officers' liability insurance and acquisition outcomes. Journal of Financial Economics, 102(3), 507-525.

Lin, C., Officer, M. S., Schmid, T., & Zou, H. (2019). Is skin in the game a game changer? Evidence from mandatory changes of D&O insurance policies. Journal of Accounting and Economics, 68(1), 101225.

Lin, C., Officer, M. S., Wang, R., & Zou, H. (2013). Directors' and officers' liability insurance and loan spreads. Journal of Financial Economics, 110(1), 37-60.

Lin, F. Y., Guan, L., Ho, C. L., & Wang, T. S. (2022). Examining the D&O insurance effect on managerial ability. Finance Research Letters, 46, 102297.

Liu, S., & Wang, Y. (2023). Green innovation effect of pilot zones for green finance reform: Evidence of quasi natural experiment. Technological Forecasting and Social Change, 186, 122079.

Liu, S., Xu, R., & Chen, X. (2021). Does green credit affect the green innovation performance of high-polluting and energy-intensive enterprises? Evidence from a quasi-natural experiment. Environmental Science and Pollution Research, 28, 65265-65277.

Liu, Z., Deng, Z., He, G., Wang, H., Zhang, X., Lin, J., ... & Liang, X. (2022). Challenges and opportunities for carbon neutrality in China. Nature Reviews

Electronic copy available at: https://ssrn.com/abstract=4630608

Earth & Environment, 3(2), 141-155.

Lo, S. M., & Shiah, Y. A. (2016). Associating the motivation with the practices of firms going green: the moderator role of environmental uncertainty. Supply Chain Management: An International Journal, 21(4), 485-498.

Lyu, M., Sun, X. C., & Wang, B. (2023). Chief audit executive as supervisory board member and executive compensation contracts. Abacus, 59(1), 258-299.

Maury, B. (2006). Family ownership and firm performance: Empirical evidence from Western European corporations. Journal of Corporate Finance, 12(2), 321-341.

O'Sullivan, N. (1997). Insuring the agents: The role of directors' and officers' insurance in corporate governance. Journal of Risk and Insurance, 545-556.

Oussii, A.A., & Boulila Taktak, N. (2018). The impact of internal audit function characteristics on internal control quality. Managerial Auditing Journal, 33(5), 450-469.

Peng, W., Lu, S., & Lu, W. (2022). Green financing for the establishment of renewable resources under carbon emission regulation. Renewable Energy, 199, 1210-1225.

Petrovits, C., Shakespeare, C., & Shih, A. (2011). The causes and consequences of internal control problems in nonprofit organizations. The Accounting Review, 86(1), 325-357.

Porter, M. E. (1991). America's green strategy. Scientific America, 264, 168.

Porter, M.E. & van der Linde, C. (1995). Towards a new conception of the environmental-competitiveness relationship. Journal of Economic Perspectives, 9, 97–118.

Priest, G.L. (1987). The current insurance crisis and modern tort law. The Yale Law Journal, 96(7), 1521-1590.

Qi, B., Li, L., Zhou, Q., & Sun, J. (2017). Does internal control over financial reporting really alleviate agency conflicts?. Accounting and Finance, 57(4), 1101-1125.

Ren, H., Zhou, W., & Gao, W. (2012). Optimal option of distributed energy systems for building complexes in different climate zones in China. Applied Energy, 91(1), 156-165.

Sharpe, W.F. (1964). Capital asset prices: A theory of market equilibrium under conditions of risk. Journal of Finance, 19(3), 425-442.

Shi, B., Li, N., Gao, Q., & Li, G. (2022). Market incentives, carbon quota allocation and carbon emission reduction: evidence from China's carbon trading pilot policy. Journal of Environmental Management, 319, 115650.

Sun, H., Edziah, B. K., Sun, C., & Kporsu, A. K. (2019). Institutional quality, green innovation and energy efficiency. Energy policy, 135, 111002.

Sun, X., Cifuentes-Faura, J., Xiao, Y., & Liu, X. A good name is rather to be chosen: The impact of CEO reputation incentives on corporate green innovation. Business Strategy and the Environment.

Electronic copy available at: https://ssrn.com/abstract=4630608

Tang, B. J., Wang, X. Y., & Wei, Y. M. (2019). Quantities versus prices for best social welfare in carbon reduction: A literature review. Applied Energy, 233, 554-564.

Tang, Y., Ho, K. C., Wu, J., Zou, L., & Yao, S. (2023). Directors and officers liability insurance and maturity mismatch: evidence from China. Applied Economics, 55(32), 3747-3765.

Touboulic, A., Matthews, L., & Marques, L. (2018). On the road to carbon reduction in a food supply network: a complex adaptive systems perspective. Supply Chain Management: An International Journal, 23(4), 313-335.

Truong, Y., Mazloomi, H., & Berrone, P. (2021). Understanding the impact of symbolic and substantive environmental actions on organizational reputation. Industrial Marketing Management, 92, 307-320.

Walls, J. L., & Berrone, P. (2017). The power of one to make a difference: How informal and formal CEO power affect environmental sustainability. Journal of Business Ethics, 145, 293-308.

Wang, D., Guo, L., & Xing, S. (2023b). Compulsory liability insurance and excess cash holdings: Evidence from China. International Review of Financial Analysis, 103011.

Wang, H., Li, Y., Lin, W., & Wei, W. (2023a). How does digital technology promote carbon emission reduction? Empirical evidence based on e-commerce pilot city policy in China. Journal of Environmental Management, 325, 116524.

Wang, J., Zhang, J., Huang, H., & Zhang, F. (2020b). Directors' and officers' liability insurance and firm innovation. Economic Modelling, 89(7), 414-426.

Wang, K., & Wu, C. (2023). Directors' and officers' liability insurance and corporate misconduct: Evidence from China. Applied Economics, 55(20), 2349-2365.

Wang, Y., & Chen, C. W. (2016). Directors' and officers' liability insurance and the sensitivity of directors' compensation to firm performance. International Review of Economics & Finance, 45, 286-297.

Wang, Y., Yang, H., & Sun, R. (2020a). Effectiveness of China's provincial industrial carbon emission reduction and optimization of carbon emission reduction paths in "lagging regions": Efficiency-cost analysis. Journal of Environmental Management, 275, 111221.

Wurlod, J. D., & Noailly, J. (2018). The impact of green innovation on energy intensity: An empirical analysis for 14 industrial sectors in OECD countries. Energy Economics, 71, 47-61.

Xia, C., Yang, J., Yang, Z., & Chan, K. C. (2023). Do directors with foreign experience increase the corporate demand for directors' and officers' liability insurance? Evidence from China. Economic Modelling, 119, 106146.

Xu, H., Pan, X., Li, J., Feng, S., & Guo, S. (2023). Comparing the impacts of carbon tax and carbon emission trading, which regulation is more effective?. Journal of Environmental Management, 330, 117156.

Xu, L., Fan, M., Yang, L., & Shao, S. (2021). Heterogeneous green innovations and

Electronic copy available at: https://ssrn.com/abstract=4630608

carbon emission performance: evidence at China's city level. Energy Economics, 99, 105269.

Yang, S. A., Bakshi, N., & Chen, C. J. (2021). Trade credit insurance: Operational value and contract choice. Management Science, 67(2), 875-891.

Yang, Z., Lu, M., Shao, S., Fan, M., & Yang, L. (2023). Carbon regulation and economic growth: City-level evidence from China. Environmental Impact Assessment Review, 99, 107020.

Yermack, D. (1996). Higher valuation of companies with a small board of directors. Journal of Financial Economics, 40, 185-212.

Yin, Z., Peng, H., Xiao, Z., Fang, F., & Wang, W. (2022). The carbon reduction channel through which financing methods affect total factor productivity: mediating effect tests from 23 major carbon-emitting countries. Environmental Science and Pollution Research, 29(43), 65012-65024.

Yu, F.F. (2008). Analyst coverage and earnings management. Journal of Financial Economics, 88(2), 245-271.

Yuan, R., Sun, J., & Cao, F. (2016). Directors' and officers' liability insurance and stock price crash risk. Journal of Corporate Finance, 37, 173-192.

Zhang, W., Li, J., Li, G., & Guo, S. (2020). Emission reduction effect and carbon market efficiency of carbon emissions trading policy in China. Energy, 196, 117117.

Zhang, X., Huang, S., Li, W., & Wang, Y. (2023). Directors' and officers' liability insurance, environmental regulation and firms' environmental responsibility. Ecological Economics, 208, 107796.

Zhang, X., Karplus, V. J., Qi, T., Zhang, D., & He, J. (2016). Carbon emissions in China: How far can new efforts bend the curve?. Energy Economics, 54, 388-395.

Zhang, Z., Zhang, B., & Jia, M. (2022). The military imprint: The effect of executives' military experience on firm pollution and environmental innovation. The Leadership Quarterly, 33(2), 101562.

Zhao, X., Liu, C., Sun, C., & Yang, M. (2020). Does stringent environmental regulation lead to a carbon haven effect? Evidence from carbon-intensive industries in China. Energy Economics, 86, 104631.

Zhao, X., Ma, X., Chen, B., Shang, Y., & Song, M. (2022). Challenges toward carbon neutrality in China: Strategies and countermeasures. Resources, Conservation and Recycling, 176, 105959.

Zhou, Y., Yang, J., & Jia, Z. (2023). Optimizing energy efficiency investments in steel firms: A real options model considering carbon trading and tax cuts during challenging economic conditions. Resources Policy, 85, 104042.

Zou, H., Wong, S., Shum, C., Xiong, J., & Yan, J. (2008). Controlling-minority shareholder incentive conflicts and directors' and officers' liability insurance: evidence from China. Journal of Banking and Finance, 32(12), 2636-2645.

Electronic copy available at: https://ssrn.com/abstract=4630608