

Research on Directors' and Officers' Liability Insurance and Enterprise Green Innovation

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Abstract. In the light of the fact that the current green wave is in vogue and the world is entering a "green" competition era, the green transformation of enterprises is to be found in urgent need. Taking China, A-share listed companies from 2011 to 2020 as the research sample, this paper empirically finds that Directors' and Officers' Liability Insurance (D&O Insurance) has a promoting effect on enterprise green innovation, and the longer the introduction time, the more obvious the effect is, which is still valid after alleviating endogenous problems and carrying out a robustness test. Through further research, this paper additionally discovers that D&O Insurance has a significant and relatively stable promoting effect on the invention-type green innovation and utility model green innovation; the promotion effect is more obvious in large-scale enterprises; it is the risk tolerance level that contributes to strengthening the effect. The research results play a role as a catalyst for the circulation of D&O Insurance, provide relevant suggestions for enterprises, regulators and the government to promote green innovation, and help China achieve a crucial position in the "green" competition era.

Keywords: Directors' and Officers' Liability Insurance; Enterprise Green Innovation; Invention-type Green Innovation; Utility Model Green Innovation; Large-scale Enterprises; Risk Tolerance Level.

1. Introduction

At present, the world has come into the era of "green" competition, and China is in a new stage of development driven by and led by innovation. Green innovation is a major strategic task for a long period in the future. It is the key driving force to change the mode of economic progress and realize green sustainable development, and it is also an important support for China to achieve the double carbon target. As the fulcrum of the micro-economy and the main body of environmental pollution, enterprises are the most critical factor to coordinate economic development with ecological environment protection [1] and should undertake the task of promoting green innovation [2]. In recent years, China's green technology innovation activities have got more and more active. From 2014 to 2017, the average annual growth rate of green patent applications was 3.7 percentage points higher than the overall average growth rate of invention patents [3]. Through green innovation, the environmental pollution of enterprises can boil down, and environmental performance can be effectively improved. More importantly, green innovation of enterprises promotes green differentiated products, which can effectively enhance their green competitiveness, and the economic efficiency of enterprises and environmental protection can achieve a "win-win" [4]. There are many kinds of research on the driving factors and effects of corporate green innovation, among which the researches on the driving factors are more in-depth and richer. Researches pay more attention to the impact of environmental regulations on corporate green innovation, such as the responsibility system for environmental protection objectives [5] and the environmental protection tax reform [6].

As an emerging external governance mechanism, Directors' and Officers' Liability Insurance (referred to as "D&O Insurance") is designed for corporate executives, which is an insurance that a company use to assume the corresponding compensation liabilities when corporate directors and senior executives are held liable for dereliction of duty or improper performance of duties [7]. It is an influential risk hedging and loss compensation tool. In recent years, with the continuous improvement of laws and regulations, the awareness of stakeholders' protection of listed companies has been rising, and the risks of professional responsibilities faced and assumed by directors and senior executives

have been increasing. As a result, the innovation and pioneering work of directors and senior executives have been restrained to a certain extent, which generates the trend that D&O insurance has been regarded as a professional effective risk management tool by the company's management. In 2020, 170 A-share listed companies have been newly insured for D&O insurance [8]. At the same time, people from all walks of life have been paying more and more attention to the governance of D&O insurance [9]. However, currently, the insurance coverage rate of D&O insurance in our country is relatively low, which is far behind the developed market [10]. As the potential for future development is huge, it is of far-reaching significance to explore it.

To sum up, it can be observed that the green transformation of enterprises is urgent, green innovation has high risks, and D&O insurance is a governance mechanism that receives more and more attention. What is the link between D&O insurance and green innovation of enterprises? According to the existing literature, the academic circle is still disputing the governance role of D&O insurance. Numerous empirical studies have found the positive benefits that D&O insurance can bring. The main viewpoints are the management incentive hypothesis, external supervision hypothesis, and information transmission hypothesis. However, there is not any lack of opposition from the academic circles. Built on the moral hazard hypothesis, D&O insurance may inhibit the green innovation of enterprises. In addition, these studies focus on the impact of D&O insurance on corporate innovation, and little literature has conducted in-depth research on the relationship between D&O insurance and corporate green innovation. With the imperative demand for green transformation and the increasing attention paid to D&O insurance, the impact of D&O insurance on green innovation will be a research topic with higher practical significance.

This paper takes China A-share listed companies from 2011 to 2020 as the research object to empirically verify the impact of D&O insurance on corporate green innovation. It found that D&O insurance has a promoting effect on corporate green innovation, and the longer it is introduced, the more noticeable the effect will be. The conclusion is still valid after alleviating endogenous problems and carrying out the robustness test. Through further research, this paper finds out that D&O insurance has a significant and relatively stable promoting effect on both invention-type green innovation and utility model green innovation; the promotion effect is more significant in large-scale enterprises; the risk tolerance level is a key element to promote the effect.

At present, after examining the impact of D&O insurance on corporate green innovation, researchers have mainly conducted a heterogeneity analysis of ownership concentration [11] and internal control intermediary effect analysis [12]. Compared with the existing literature, the contribution of this paper is mainly reflected in the following three aspects. Firstly, the introduction time of D&O insurance is taken into consideration, which enriches the impact dimension of D&O insurance on green innovation. It is discovered that the longer the introduction time, the more observable the positive impact. Secondly, by subdividing the explained variables, it is found that the D&O insurance has a significant and relatively stable promoting effect on the invention-type green innovation and the utility model green innovation. Thirdly, the paper explores the mechanism of promoting green innovation by D&O insurance and finds that the risk tolerance level is crucial for promoting the effect.

2. Literature Review

2.1 Research on Green Innovation

At present, research on corporate green innovation can be divided into two directions, namely, the effect of different influencing factors on corporate green innovation and the effect that corporate green innovation can bring.

In the research on the influencing factors of enterprise green innovation, "hard supervision" and "soft supervision" are crucial. Among them, "hard supervision" mainly refers to the government's environmental regulations, such as the environmental protection target responsibility system [5] and environmental protection tax reform [6]. Generally speaking, most of the environmental regulation

tools play a positive role in promoting the green innovation of enterprises [4,13-15], but there are a few scholars believe that environmental regulation does not bring additional innovation incentives [16], or even inhibit innovation efficiency [17]. Guo Jin stated that the key to the success of environmental regulation in promoting green innovation lies in the choice of regulatory tools [18]. On how "soft regulation" interferes with the green innovation of enterprises, scholars have conducted research from the perspectives of environmental information disclosure [19], ESG information disclosure [20], and market soft regulation [21]. In addition to "soft and hard supervision", corporate social responsibility also has an impact on green innovation [22]; the global trend of digitalization is prominent, and technological empowerment has a significant impact on green innovation [23]; the development of the green economy is unprecedented. As one of the important pillars of the green economy, green finance can effectively promote green innovation [24,25].

With regard to the effects that green innovation can bring to enterprises, from a micro point of view, green innovation can help enterprises to reduce environmental costs and seize green competitive advantages [26], further stimulate the research and development and production of green differentiated products and effectively enhance the green competitiveness of enterprises, which is conducive to achieving a "win-win" situation between enterprise competitiveness and environmental protection [4,27]. From a macro perspective, green innovation is an important element in coordinating economic growth with environmental protection [28].

2.2 Research on D&O Liability Insurance

As an eminent corporate governance mechanism, the relevant research on D&O Insurance focuses on its governance effect. However, academia has not yet reached a unified conclusion on whether its governance effect is positive or negative.

On the one hand, many studies show that D&O insurance has a positive governance effect in diverse aspects. D&O Insurance can introduce the underwriting company as an external supervisor into the corporate governance environment [29], thus significantly reducing the tendency of the company to violate the rules [30]. Moreover, with incentive effect and supervision effect [31], it improves the level of corporate governance [8]. Meanwhile, subscription to D&O insurance will significantly improve the level of corporate risk bearing capacity [32] and improve the ability to obtain credit resources and the quality of information disclosure [9], thus enhancing the innovation capability; it will effectively improve the innovation efficiency and innovation quality of enterprises to increase innovation output [7,33,34]. Plus, the longer it is taken to introduce D&O insurance, the more beneficial it will be to corporate innovation [34]. A small number of studies involved the influence of D&O insurance on green innovation [11,12] and some of them only focus on manufacturing enterprises.

On the other hand, the governance mechanism of D&O insurance does have adverse effects. D&O insurance can induce executives' opportunistic behaviors and risk decisions, which will harm corporate value [35-37], aggravate the business risk of the enterprise [10], and convey the signal that the enterprise is at risk to the outside world [38].

2.3 Summary and Comment

Through the analysis of the relevant research on green innovation and D&O insurance, it can be seen that the research on corporate green innovation mainly focuses on its influencing factors and functions, especially on the impact of environmental regulations on green innovation, and the research on external influencing factors of enterprises is in the majority. Focusing on its governance effect, from different perspectives, the positive and negative effects of D&O insurance coexist, which is controversial. A large number of studies have shown that D&O insurance will affect corporate innovation, but the relationship between them remains unclear. The research on whether D&O insurance can promote corporate green innovation is still less involved. As the combination of innovation development and green development, corporate green innovation has capital sinking and irreversibility, and the uncertainty is more sizable. Based on the new stage of development, the "green

waves” have occurred one after another, and the green transformation of enterprises is urgent, while D&O insurance is a critical corporate governance mechanism. Exploring the relationship between D&O insurance and the green innovation of enterprises is of significant benefit to the green transformation of enterprises in China.

2.4 Theoretical Analysis and Research Assumptions

According to the existing literature research, aiming at the influence of D&O insurance, the academic circle has mainly formed four theories as following. They are management incentive hypothesis, external supervision hypothesis, information transmission hypothesis and moral hazard hypothesis.

The management incentive hypothesis holds that the introduction of D&O insurance improves the management's risk tolerance and commitment level, encourages them to actively invest in high-risk innovation research and development, and has an innovation incentive effect [29,32,33]. Moreover, Priest also found that after subscribing to the D&O insurance, it is easier for enterprises to identify and attract highly qualified managers to join the team, thus enhancing the quality of innovation decision-making and innovation efficiency [39]. Therefore, we expect that according to the management incentive hypothesis, the management will increase the level of risk commitment and active investment in high-risk green innovation research and development. Simultaneously, the addition of high-quality managers will also improve the quality of innovation decision-making, and more green innovation decisions will be made. Hence, D&O insurance can promote the green innovation of enterprises.

According to the external supervision hypothesis, after subscribing to the D&O insurance, the insurance company becomes a stakeholder, which will act as an external supervisor to supervise and restrain the enterprise, significantly reducing the probability of the company's non-compliance and having a supervision effect [29-31,38]. Therefore, we expect that under the external supervision hypothesis, the insurance companies can supervise the enterprises to carry out green innovation and reduce the environmental risks of the enterprises. So, D&O insurance is worthwhile to promote the enterprises to carry out green innovation.

Based on the information transmission hypothesis, the oversight role of D&O insurance can improve corporate governance, which can send a positive signal to investors, alleviate the adverse selection of innovation activities and moral hazard problems caused by information asymmetry, and improve the quality of information disclosure, thus effectively promoting corporate innovation [9]. Therefore, we expect that starting from the information transmission hypothesis, corporate governance will be improved; investors will accept positive signals and favor enterprises more; enterprises will have more capital strength to research and develop green innovation under the condition of better acceptance of investment. Thereby, D&O insurance will improve the level of green innovation of enterprises.

Different from the above three hypotheses' positive evaluation of the effects of D&O insurance, the moral hazard hypothesis instead believes that under the protection of the risks of D&O insurance, the management will be more likely to pursue the maximization of personal interests when implementing innovation decisions, thus increasing the encroachment on innovation resources and shareholders' interests and significantly reducing the allocation efficiency of innovation resources. In the meantime, the moral hazard of senior executives increases, and the probability of opportunistic behaviors catering to investment increases, which has a negative impact on corporate value and innovation [7,34-37]. Thereby, we expect that with the moral hazard hypothesis, managers will pursue the maximization of personal interests when making green innovation decisions, which will significantly reduce the allocation efficiency of green innovation resources. At the same time, the probability of opportunistic behavior will increase, which will hurt corporate value and green innovation. Accordingly, D&O insurance may also do harm to corporate green innovation.

In conclusion, the impact of D&O insurance on corporate green innovation continues to be controversial, which means that it is unknown whether its impact is positive or negative. Hence, this paper puts forward the following opposite assumptions:

H₀: The impact of D&O insurance on corporate green innovation is positive;

H₁: The impact of D&O insurance on corporate green innovation is negative.

3. Research Design

3.1 Model Setting

This paper investigates the impact of D&O insurance on corporate green innovation through model (1), and the model is set as follows:

$$GI_{i,t} = \beta_0 + \beta_1 DO_{i,t}(Time_{i,t}) + \beta_n Controls + \sum Year + \sum Industry + \varepsilon_{i,t} \tag{1}$$

Among this model, $GI_{i,t}$ represents the green innovation level of the enterprise; $DO_{i,t}$ represents whether the enterprise purchases D&O insurance; $Time_{i,t}$ represents the introduction time of D&O insurance. The control variables include enterprise size, capital structure, asset yield, cash flow level, enterprise growth, enterprise research and development investment intensity, fixed asset interest rate, historical performance, market power, and management incentives. This paper concentrates on the coefficient of β_1 . If the impact of D&O insurance on green innovation is positive, β_1 should be found to be significantly positive, otherwise β_1 should be found to be significantly negative. In addition, this paper also controls the year and industry fixed effect. Year and industry are virtual variables of year and industry fixed effect respectively. And $\varepsilon_{i,t}$ is the random error term of the model.

3.2 Variable Definition

Table 1. Variable definition

Interpreted variable	
<i>LnGI_all</i>	The green innovation level of the enterprise. The natural logarithm of the whole of the number of green inventions applied in the current year, the number of green utility models and 1.
Explanatory variable	
<i>DO</i>	The purchase of corporate D&O insurance. If it is purchased in the current year, 1 is taken; otherwise, 0 is taken.
<i>Time</i>	The length of time that the enterprise introduces D&O insurance. The natural logarithm of the whole of the number of years that D&O insurance introduces and 1.
Control variable	
<i>Size</i>	The size of the enterprise. The natural logarithm of the total assets of the enterprise.
<i>Lev</i>	Capital structure. Total liabilities/total assets.
<i>Roa</i>	Return on assets. Net profit/total assets.
<i>Cfo</i>	Cash flow level. Net cash flows from operating activities/total assets.
<i>Growth</i>	Corporate growth. (Current operating income–prior operating income)/prior operating income.
<i>GI_input</i>	Enterprise R&D input intensity. R&D input/operating income.
<i>Far</i>	Fixed assets interest rate. Net fixed assets/total assets.
<i>Lroa</i>	Historical performance. Net profit of previous period/total assets of previous period.
<i>Market</i>	Market power. Natural logarithm of sales revenue/operating costs.
<i>Share</i>	Management incentives. Management shareholding/total share capital of the company.
<i>Year</i>	Year fixed effect.
<i>Industry</i>	Industry fixed effect.

A detailed description of each variable in the model (1) is shown in Table 1.

1) *Interpreted variable*: Corporate Green Innovation Level (*GI*). Referring to the existing research, this paper collects the data on current green invention patents and utility model patent applications from the China Research Data Service Platform (CNRDS) database, adds them together as the current total green patent applications, and takes the log processing (*LnGI_all*) after plus 1 as the regression model to measure the green innovation level of enterprises [40]. Since there is a period lag between patent application and authorization, the amount of patent application is adopted instead of the amount of authorization.

2) *Explanatory variable*: Referring to the practice of Ling Shixian and Liu Ao, firstly, this paper uses the virtual variable *DO* to represent the purchase of D&O insurance. If the board of directors of the listed company proposes and the shareholders' representative meeting votes to pass the D&O insurance bill or related information in the current year, it is regarded as the purchase of D&O insurance, with *DO* taking 1, otherwise, *DO* taking 0. At the same time, if the purchase is terminated without an explicit resolution, it is deemed as an ongoing purchase of D&O insurance. Secondly, a *Time* index is set. The variable value is the natural logarithm of the whole of the number of years of D&O insurance and 1 [34].

3) *Control variable*: According to previous scholars' research, this paper controls the following variables: enterprise size (*Size*), capital structure (*Lev*), return on assets (*Roa*), cash flow level (*Cfo*), enterprise Growth (*Growth*), enterprise R&D input intensity (*GI_input*), fixed asset interest rate (*Far*), historical performance (*Lroa*), Market power (*Market*), management incentive (*Share*). Simultaneously, the year effect and industry effect are also controlled. The specific definitions of each variable can be found in Table 1.

3.3 Samples and Data Sources

In this paper, A-share listed companies from 2011 to 2020 are selected as research samples, and the original samples are processed as follows. First, it removed ST * and ST company samples, and removed financial companies and companies with missing data. Second, in order to control the influence of outliers, 1% and 99% quartiles of the data were shrunk. After the above-mentioned processing, 16,744 annual sample observations were eventually obtained, among which 1,213 groups of observations were purchased for D&O insurance. Data on corporate green innovation are from the China Research Data Service Platform (CNRDS), and other data comes from the China Stock Market Accounting Research (CSMAR).

4. Empirical Research Results

4.1 Descriptive Statistic

Table 2. Descriptive statistic

Variable	Observed value	Mean	SD	Min	Max
LnGI_all	16744	0.270	0.684	0.000	3.497
DO	16744	0.072	0.259	0.000	1.000
Time	16744	0.101	0.387	0.000	2.079
Size	16744	22.258	1.285	19.996	26.231
Lev	16744	0.421	0.201	0.057	0.907
Roa	16744	0.035	0.070	-0.332	0.204
Cfo	16744	0.050	0.065	-0.132	0.237
Growth	16744	0.137	0.324	-0.514	1.818
GI_input	16744	0.046	0.045	0.000	0.265
Far	16744	0.216	0.147	0.004	0.658
Lroa	16744	0.040	0.065	-0.298	0.199
Market	16744	1.565	0.753	1.003	6.049
Share	16744	0.137	0.194	0.000	0.676

Descriptive statistical results for the variables are presented in Table 2. The average value of *DO* is 0.072, which means that only 7.2% of the enterprises in the sample purchased the D&O insurance, and the coverage rate was generally low. The average value of *Time* is 0.101, with a maximum value of 2.079 and a minimum value of 0, which reflects the difference in the introduction time of D&O insurance in the sample enterprises. The average value of *LnGI_all*, which measures the level of green innovation of enterprises, is 0.270, indicating that green innovation has not attracted the general attention of enterprises. Meanwhile, its maximum value is 3.497 and the minimum value is 0, indicating that there is a great difference in the level of green innovation among the sample enterprises. In addition, the descriptive statistics of the remaining control variables are within the normal range, illustrating that the variables are no longer affected by the extreme values after Winsorize processing.

4.2 Single Variable Analysis

In this paper, the total sample is divided into an experimental group (*DO*=1) and a control group (*DO*=0) according to the virtual variable (*DO*) of whether to purchase D&O insurance. The test results for the difference between the mean values of the two grouped explanatory variables (*LnGI_all*) are shown in Table 3. According to it, the average value of green innovation level, which is significant at 1%, in the experimental group is greater than that in the control group. The results initially indicate that the listed companies' purchase of D&O insurance may help to improve the level of green innovation.

Table 3. Single Variable Analysis: Mean T Test

Variable	Experimental Group (DO=1)		Control Group (DO=0)		Mean T Test
	Sample size	average/ mean value	Sample size	average/ mean value	
LnGI_all	1213	0.649	15531	0.240	-20.279***

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, the same goes for the following

4.3 Principal Regression Results

Table 4. The Regression Result of D&O Insurance Purchase and Green Innovation Level

Variable	(1)	(2)	(3)	(4)
	LnGI_all	LnGI_all	LnGI_all	LnGI_all
DO	0.409*** (0.020)	0.165*** (0.019)	0.367*** (0.020)	0.167*** (0.019)
Size		0.223 (0.005)		0.236 (0.005)
Lev		-0.027 (0.033)		-0.137*** (0.033)
Roa		0.271*** (0.092)		0.102 (0.090)
Cfo		-0.098 (0.085)		-0.020 (0.084)
Growth		0.017 (0.016)		-0.012 (0.015)
GI_input		1.968*** (0.122)		1.109*** (0.139)
Far		-0.100*** (0.035)		-0.063 (0.041)
Lroa		0.073 (0.090)		-0.014 (0.088)
Market		-0.079*** (0.007)		-0.043*** (0.008)
Share		0.010 (0.027)		-0.043 (0.027)
Cons	0.240 (0.005)	-4.649 (0.101)	-0.137 (0.155)	-5.088*** (0.177)
Year	No	No	Yes	Yes
Industry	No	No	Yes	Yes
N	16744	16744	16744	16744
R-Square	0.024	0.182	0.123	0.252

Table 4 and Table 5 show the empirical consequences of the impact of D&O insurance on corporate green innovation. As can be seen from Table 4, the virtual variable *DO*, which indicates whether to purchase the D&O insurance, is significantly positive at the level of 1%, meaning that the enterprises purchasing the D&O insurance have a higher level of green innovation. As can be seen from Table 5, the introduction Time of D&O insurance is also significant at 1%, reflecting that the longer the introduction time of D&O insurance, the greater its positive effect. In conclusion, hypothesis H_0 in this paper can be verified. Specifically, the impact of D&O insurance on corporate green innovation is positive, and the longer the introduction of D&O insurance, the greater its constructive role.

Table 5. The Regression Result of the Introduction Duration of D&O Insurance and Green Innovation Level

Variable	(5)	(6)	(7)	(8)
	LnGI all	LnGI all	LnGI all	LnGI all
Time	0.297***	0.130***	0.266***	0.130***
	(0.013)	(0.013)	(0.013)	(0.013)
Size		0.221		0.235
		(0.005)		(0.005)
Lev		-0.024		-0.135***
		(0.033)		(0.033)
Roa		0.269***		0.097
		(0.092)		(0.090)
Cfo		-0.099		-0.019
		(0.085)		(0.084)
Growth		0.017		-0.012
		(0.016)		(0.015)
GI input		1.957***		1.101***
		(0.122)		(0.139)
Far		-0.099***		-0.062
		(0.035)		(0.041)
Lroa		0.074		-0.015
		(0.090)		(0.088)
Market		-0.078***		-0.043***
		(0.007)		(0.008)
Share		0.013		-0.041
		(0.027)		(0.027)
Cons	0.240	-4.614	-0.135	-5.061***
	(0.005)	(0.101)	(0.154)	(0.176)
Year	No	No	Yes	Yes
Industry	No	No	Yes	Yes
N	16744	16744	16744	16744
R-Square	0.028	0.183	0.126	0.253

4.4 Endogeneity Test

There may be an endogenous problem of self-selection bias when enterprises purchase D&O insurance. To eliminate the interference, this paper uses Heckman's two-stage approach to test the main regression results. If the proportion of other companies in the same industry purchasing D&O insurance is high, the company itself will get stimulated to purchase D&O insurance to a certain extent. Meanwhile, the company is not directly affected by the situation of other companies in the same industry purchasing D&O insurance. Hence, the proportion of other companies in the same industry purchasing D&O insurance not only meets the correlation requirements of the instrument variables but also meets the exogenous requirements of the instrument variables. Therefore, the proportion of other companies in the same industry purchasing D&O insurance (*Other_DO*) is selected as the exogenous instrument variable [11].

The specific steps are as follows: in the first stage, set the buying situation (*DO*) of D&O insurance and the introduction Time (*Time*) of D&O insurance as the explained variables, then add *Other DO*, performing regression analysis by using a Probit model, and obtain an inverse mills ratio (*Imr*) according to the regression result; inverse mills ratio (*Imr*) is added to the Heckman stage 2 model for fitting, and the regression results are shown in TABLE VI. From the regression results, it can be seen that the impact coefficients of *DO* and *Time* are still positive at the significance level of 1%, and the other control variables are within the normal range. The test results still support the core regression conclusion.

Table 6. The regression results of Heckman's two-stage model

Variable	(1)	(2)
	LnGI_all	LnGI_all
DO	0.174***	
	(0.019)	
Time		0.132***
		(0.013)
Size	0.265***	0.260***
	(0.008)	(0.008)
Lev	-0.139***	-0.136***
	(0.033)	(0.033)
Roa	0.062	0.060
	(0.092)	(0.092)
Cfo	0.026	0.023
	(0.085)	(0.085)
Growth	-0.015	-0.014
	(0.016)	(0.016)
GI_input	1.017***	1.018***
	(0.142)	(0.142)
Far	-0.100**	-0.096**
	(0.042)	(0.042)
Lroa	-0.093	-0.085
	(0.092)	(0.092)
Market	-0.037***	-0.037***
	(0.009)	(0.009)
Share	-0.187***	-0.168***
	(0.046)	(0.046)
Imr	0.109***	0.097***
	(0.028)	(0.028)
Cons	-5.934***	-5.821***
	(0.270)	(0.270)
Year	Yes	Yes
Industry	Yes	Yes
N	16394	16394
R-Square	0.253	0.254

4.5 Robustness Test

Change the measurement of the explained variable: Referring to the practice of Qi Shaozhou et al. [40], this paper uses the ratio of green invention patent application volume to innovation patent application volume (*Glinv_rate*) as the proxy variable of the enterprise's green innovation level, replaces the original index for testing, and obtains the robustness results as shown in column (1) in Table 7. The results showed that the regression coefficient of *DO* was always positive at the significance level of 1%, which was consistent with the main regression results.

Removing samples with weak correlation with Green innovation: Considering the particularity of green innovation activities, on accounts of the Guidance on Industry Classification of Listed Companies issued by the CSRC in 2012, this paper excludes some major categories with weak relevance to green innovation from the seven categories (the industries excluded in this paper include

wholesale industry (F51), retail industry (F52), postal industry (G60), accommodation industry (H61), catering industry (H62), real estate industry (K70), health industry (Q83), social work industry (Q84), education industry (P82), culture, sports and entertainment industry (category R)). The regression results are shown in columns (2) and (3) in Table 7. From the regression results, the regression coefficients of *DO* and *Time* are still positive at the significance level of 1%, and there is no significant difference with the main regression results.

Table 7. Robustness test results

Variable	(1)	(2)	(3)
	Glinv rate	LnGI all	LnGI all
DO	0.041***	0.174***	
	(0.009)	(0.019)	
Time			0.136***
			(0.013)
Size	0.072***	0.244	0.243
	(0.002)	(0.005)	(0.005)
Lev	-0.035**	-0.150***	-0.148***
	(0.015)	(0.034)	(0.034)
Roa	0.066	0.096	0.091
	(0.041)	(0.093)	(0.093)
Cfo	-0.013	-0.025	-0.024
	(0.038)	(0.086)	(0.086)
Growth	0.006	-0.010	-0.010
	(0.007)	(0.016)	(0.016)
GI input	0.613***	1.093***	1.087***
	(0.064)	(0.141)	(0.141)
Far	-0.046**	-0.075*	-0.073*
	(0.019)	(0.042)	(0.042)
Lroa	0.079*	-0.023	-0.024
	(0.040)	(0.091)	(0.091)
Market	-0.016***	-0.045***	-0.044***
	(0.004)	(0.009)	(0.009)
Share	-0.052***	-0.035	-0.033
	(0.012)	(0.027)	(0.027)
Cons	-1.518***	-5.273***	-5.244***
	(0.081)	(0.184)	(0.184)
Year	Yes	Yes	Yes
Industry	Yes	Yes	Yes
N	16744	16270	16270
R-Square	0.128	0.256	0.257

In summary, the estimation results are consistent with the main regression results, regardless of changing the measurement method of the explained variables or excluding the samples with weak correlation with green innovation. For this reason, it is indicated that the impact of D&O insurance on corporate green innovation is positive, and the conclusion that the longer the introduction of D&O insurance, the greater the positive role it plays is robust.

5. Further Analysis

5.1 The Promotion Effect of D&O Insurance on Green Innovation of Different Quality

The fundamental point and core direction to improve the level of green innovation in enterprises is to improve the quality of green innovation. There are three types of patents in China, namely invention patents, utility model patents, and design patents. At present, patents related to green innovation are mainly focused on invention patents and utility model patents, among which, due to

the characteristics of higher technical content, stronger novelty, and newer methods, compared with utility model patents, invention patents can better reflect the quality of innovation output [7]. From the above analysis, it can be concluded that D&O insurance is helpful to improve the overall green innovation level of the enterprise, but how it promotes green innovation of different quality is unknown. Therefore, this paper further divides corporate green innovation into invention based green innovation and utility model based green innovation and carries out regression analysis to investigate the promotion effect of D&O insurance on these two kinds of green innovation.

In this paper, the index *LnGI_inv* is used to measure the enterprise's invention-type green innovation, which is specifically defined as the natural logarithm of the whole of the number of invention-type green patents applied by the enterprise in the current year and 1. The regression analysis results are presented in Table 8 and Table 9.

According to columns (1) and (5), when no control variable is added, the regression coefficient of the influence of *DO* on the inventive green innovation is still positive at a significant level of 1%, even if the year effect and industry characteristics are not considered, indicating that D&O insurance can promote the inventive green innovation without considering these factors. It can be seen from columns (3) and (7) that when no control variable is added but the year effect and industry effect are controlled, D&O insurance can also promote the invention-type green innovation. According to columns (2), (6) and (4), (8), after adding the control variables, regardless of whether the year effect and industry effect are controlled or not, D&O insurance can still promote the inventive green innovation. On the whole, the role of D&O insurance in promoting innovation-oriented green innovation is relatively stable and less affected by additional factors.

Table 8. Regression Analysis on the Purchase of D&O Insurance and Innovative Green Innovation

Variable	(1)	(2)	(3)	(4)
	LnGI_inv	LnGI_inv	LnGI_inv	LnGI_inv
DO	0.344*** (0.016)	0.156*** (0.016)	0.312*** (0.016)	0.156*** (0.015)
Size		0.176 (0.004)		0.188 (0.004)
Lev		-0.056** (0.027)		-0.141*** (0.027)
Roa		0.205*** (0.075)		0.074 (0.074)
Cfo		-0.049 (0.069)		-0.006 (0.069)
Growth		0.013 (0.013)		-0.007 (0.013)
GI input		1.630*** (0.100)		0.969*** (0.115)
Far		-0.109*** (0.029)		-0.077** (0.034)
Lroa		0.050 (0.074)		-0.006 (0.073)
Market		-0.061*** (0.006)		-0.037*** (0.007)
Share		-0.001 (0.022)		-0.039* (0.022)
Cons	0.177 (0.004)	-3.661 (0.083)	-0.077 (0.127)	-3.982*** (0.146)
Year	No	No	Yes	Yes
Industry	No	No	Yes	Yes
N	16744	16744	16744	16744
R-Square	0.026	0.170	0.109	0.230

Table 9. Regression Analysis on the Introduction Duration of D&O Insurance and Innovative Green Innovation

Variable	(5)	(6)	(7)	(8)
	LnGI inv	LnGI inv	LnGI inv	LnGI inv
Time	0.248***	0.119***	0.225***	0.119***
	(0.011)	(0.010)	(0.011)	(0.010)
Size		0.174		0.186
		(0.004)		(0.004)
Lev		-0.054**		-0.140***
		(0.027)		(0.027)
Roa		0.203***		0.069
		(0.075)		(0.074)
Cfo		-0.050		-0.005
		(0.069)		(0.069)
Growth		0.013		-0.006
		(0.013)		(0.013)
GI input		1.619***		0.961***
		(0.100)		(0.115)
Far		-0.108***		-0.076**
		(0.029)		(0.034)
Lroa		0.050		-0.007
		(0.074)		(0.073)
Market		-0.060***		-0.036***
		(0.006)		(0.007)
Share		0.001		-0.037*
		(0.022)		(0.022)
Cons	0.177	-3.633	-0.075	-3.960***
	(0.004)	(0.083)	(0.127)	(0.146)
Year	No	No	Yes	Yes
Industry	No	No	Yes	Yes
N	16744	16744	16744	16744
R-Square	0.030	0.172	0.112	0.231

Table 10. Regression Analysis on the Purchase of D&O Insurance and Green Innovation of Utility Model

Variable	(9)	(10)	(11)	(12)
	LnGI use	LnGI use	LnGI use	LnGI use
DO	0.245***	0.094***	0.221***	0.100***
	(0.014)	(0.013)	(0.013)	(0.013)
Size		0.135		0.143
		(0.003)		(0.004)
Lev		0.003		-0.079***
		(0.023)		(0.023)
Roa		0.137**		0.024
		(0.064)		(0.063)
Cfo		-0.080		0.017
		(0.059)		(0.058)
Growth		0.003		-0.020*
		(0.011)		(0.011)
GI input		0.866***		0.355***
		(0.085)		(0.097)
Far		-0.036		0.008
		(0.024)		(0.029)
Lroa		0.017		-0.066
		(0.063)		(0.061)
Market		-0.046***		-0.023***
		(0.005)		(0.006)
Share		0.042**		0.007
		(0.019)		(0.019)
Cons	0.124***	-2.849	-0.118	-3.103***
	(0.004)	(0.071)	(0.106)	(0.123)
Year	No	No	Yes	Yes
Industry	No	No	Yes	Yes
N	16744	16744	16744	16744
R-Square	0.019	0.144	0.122	0.221

In this paper, the index $LnGI_use$ is used to measure green innovation of the enterprise utility model, which is specifically defined as the natural logarithm of the whole of the number of utility model green patents applied by the enterprise in the current year and 1. The regression analysis results are displayed in Table 10 and Table 11.

Similarly, according to columns (9) and (13), when no control variables are added, even if the year effect and industry characteristics are not considered, the regression coefficient of the influence of DO on the green innovation of utility model is still positive at a significant level of 1%, indicating that D&O insurance can promote the green innovation of utility model without considering these factors. Depending on columns (11) and (15), when no control variable is added, D&O insurance can also promote the green innovation of the utility model by controlling the year effect and industry effect. According to columns (10), (14) and (12), (16), after adding control variables, regardless of whether the year and industry effect are controlled or not, D&O insurance can promote the green innovation of the utility model. On the whole, the role of D&O insurance in promoting green innovation of utility model is also relatively stable and less affected by other factors.

Table 11. Regression Analysis on the Introduction Duration of D&O Insurance and Green Innovation of Utility Model

Variable	(13)	(14)	(15)	(16)
	LnGI use	LnGI use	LnGI use	LnGI use
Time	0.182*** (0.009)	0.079*** (0.009)	0.164*** (0.009)	0.082*** (0.009)
Size		0.134 (0.003)		0.141 (0.004)
Lev		0.006 (0.023)		-0.078*** (0.023)
Roa		0.136** (0.064)		0.021 (0.062)
Cfo		-0.081 (0.059)		0.017 (0.058)
Growth		0.003 (0.011)		-0.020* (0.011)
GI input		0.860*** (0.085)		0.350*** (0.097)
Far		-0.035 (0.024)		0.009 (0.029)
Lroa		0.019 (0.063)		-0.066 (0.061)
Market		-0.045*** (0.005)		-0.023*** (0.006)
Share		0.044** (0.019)		0.009 (0.019)
Cons	0.123*** (0.004)	-2.821 (0.071)	-0.117 (0.105)	-3.081*** (0.123)
Year	No	No	Yes	Yes
Industry	No	No	Yes	Yes
N	16744	16744	16744	16744
R-Square	0.023	0.146	0.125	0.222

In conclusion, D&O insurance has a significant promotion effect on the invention type green innovation with higher innovation quality and the utility model type green innovation with lower innovation quality. What's more, this positive effect is relatively stable and less affected by other factors, which is beneficial to improving the overall green innovation efficiency.

5.2 The Promotion Effect of D&O Insurance on Green Innovation of Enterprises of Different Sizes

The foregoing has completely confirmed the promotion effect of D&O insurance on green innovation. However, due to the extremely high-risk of green innovation, enterprises of different sizes may consider green innovation differently in terms of capital and strategy. For example, large-scale enterprises achieve good capital strength. In the environment of green transformation, managers will have an eye on green innovation from the perspective of future development investment. For the sake of longer-term interests, they may have a higher willingness for green innovation. In addition, enterprises are also capable to bear green innovation expenses. On the contrary, small and medium-sized enterprises may choose projects with shorter payback periods and lower risks due to restricted funds, focusing on short-term benefits and not paying attention to green innovation. Therefore, the differences in the promotion effect of D&O insurance on green innovation among enterprises of different sizes also need to be explored.

Table 12. Analysis of scale heterogeneity

Variable	(1)	(2)	(3)	(4)
	large-scale LnGI all	Small and medium-sized LnGI all	large-scale LnGI all	Small and medium-sized LnGI all
DO	0.136*** (0.028)	0.016 (0.022)		
Time			0.104*** (0.018)	0.009 (0.016)
Size	0.382*** (0.010)	0.077*** (0.008)	0.380*** (0.010)	0.077*** (0.008)
Lev	-0.268*** (0.063)	0.034 (0.027)	-0.268*** (0.063)	0.034 (0.027)
Roa	-0.001 (0.184)	0.126* (0.069)	-0.004 (0.184)	0.126* (0.069)
Cfo	0.211 (0.155)	-0.099 (0.068)	0.210 (0.154)	-0.099 (0.068)
Growth	-0.009 (0.026)	0.010 (0.014)	-0.009 (0.026)	0.010 (0.014)
GI input	1.473*** (0.291)	0.799*** (0.105)	1.465*** (0.290)	0.798*** (0.105)
Far	-0.132* (0.071)	-0.122*** (0.037)	-0.129* (0.071)	-0.122*** (0.037)
Lroa	-0.055 (0.182)	0.124* (0.067)	-0.056 (0.182)	0.124* (0.067)
Market	-0.075*** (0.016)	-0.011 (0.007)	-0.074*** (0.016)	-0.011 (0.007)
Share	-0.140** (0.061)	-0.037* (0.020)	-0.136** (0.061)	-0.038* (0.020)
Cons	-8.521*** (0.372)	-1.659*** (0.200)	-8.469*** (0.372)	-1.660*** (0.200)
Year	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes
N	8372	8372	8372	8372
R-Square	0.298	0.058	0.299	0.058

Supported by the median total assets as the classification standard, this paper classifies the enterprises with assets larger than the median as large-scale enterprises, or as small and medium-scale enterprises, and further studies how D&O insurance affects green innovation in enterprises of different scales. The estimation results are given in Table 12. As can be seen from Table 12, the regression coefficient of the impact of the purchase of D&O insurance and the introduction time of D&O insurance on the green innovation of large-scale enterprises is positive under the significance

level of 1%. Thus, the promotion effect of D&O insurance on the green innovation of large-scale enterprises is obvious. However, the regression coefficient of the influence of D&O insurance variable on the green innovation of small and medium-sized enterprises is not significant, indicating that D&O insurance has not much effect on promoting the green innovation of small and medium-sized enterprises.

The reasons why the promotion effect of D&O insurance on green innovation is more significant in large-scale enterprises are probably as follows.

Firstly, from the perspective of the management incentive effect of D&O insurance, subscription of D&O insurance can make it easier for enterprises to identify and attract managers with excellent qualifications, improve the quality of innovation decision-making and innovation efficiency [40], while managers with excellent qualifications tend to have higher requirements for positions and have a stronger tendency to enter large-scale mature enterprises. On the contrary, their willingness to work in small and medium-sized enterprises is weak and their probability is minimal. Therefore, D&O insurance is more likely to improve the quality and efficiency of green innovation decision-making of large-scale enterprises.

Secondly, starting from the effectiveness of the information transmission of D&O insurance, the supervisory role of D&O insurance can send a positive signal to investors and improve the quality of information disclosure, thus effectively promoting enterprise innovation [9]. However, investors are often attracted to large-scale enterprises with larger development potential and profit space and get over small and medium-sized enterprises. Considering the high return on investment and the risk of green record-breaking, large-scale enterprises are more powerful for investors, and have a higher probability of bringing a high return on investment. They can better cope with the uncertainty and high risk of green innovation. Therefore, they will be more willing to invest in large-scale enterprises, so that the green innovation of large-scale enterprises can be effectively promoted.

Thirdly, considering the capital strength of the enterprise itself, large-scale enterprises may have higher cash flows and be able to invest in the research and development of green innovation, while small and medium-sized enterprises may not carry out the research and development of green innovation because they do not have sufficient cash flows even if they have purchased D&O insurance. Meanwhile, according to the foregoing, the longer it takes to bring in D&O insurance, the greater its contribution to green innovation. Small and medium-sized enterprises may purchase D&O insurance for a shorter period than large-sized enterprises. Therefore, the impact of D&O insurance on small and medium-sized enterprises' green innovation is equally insignificant.

5.3 The Promotion Mechanism of D&O Insurance on Enterprise Green Innovation

According to the management incentive hypothesis, the introduction of D&O insurance improves the management's risk tolerance and commitment level, encourages them to actively invest in high-risk innovation research and development, and has an innovation incentive effect [29,32,33]. Therefore, the level of risk commitment may be a key element for directors to promote green innovation. Using the three-step approach, this paper examines the specific mechanism of promoting green innovation in enterprises from the risk tolerance level. Specifically, referring to the research of Li Conggang and Xu Rong [33], this paper sets the following two models:

$$RiskTaking_{i,t} = \beta_0 + \beta_1 DO_{i,t}(Time_{i,t}) + \beta_n Controls + \sum Year + \sum Industry + \varepsilon_{i,t} \quad (2)$$

$$LnGI_all_{i,t} = \beta_0 + \beta_1 RiskTaking_{i,t} + \beta_n Controls + \sum Year + \sum Industry + \varepsilon_{i,t} \quad (3)$$

In model (2), the variable to be explained is *RiskTaking*, which means the risk tolerance level of an enterprise and is measured by the volatility of the return on equity. The volatility of the return rate refers to the standard deviation of the enterprise's industry-adjusted return rate within three or five years, where the industry-adjusted return rate is the difference between the enterprise's return rate for

the current year and the return rate of all enterprises in the industry in which the enterprise is located for the current year.

The explanatory variable in model (3) is the risk tolerance level (*RiskTaking*), and the explanatory variable is the level of green innovation (*LnGI_all*). Similarly, the volatility of the return on equity is used to measure the level of exposure. The regression analysis results of D&O risk variable and the volatility of stock return within three years and five years, the volatility of stock return within three years and five years, and corporate green innovation are shown in Table 13 and Table 14.

Table 13. Test of the risk-taking level mechanism (measured by the stock return rate within 3 years)

Variable	(1)	(2)	(3)	(4)
	The stock returns 3 years	LnGI_all	The stock returns 3 years	LnGI_all
DO	0.020** (0.010)	0.166*** (0.019)		
Time			0.015** (0.006)	0.130*** (0.013)
The stock returns 3 years		0.031** (0.015)		0.030** (0.015)
Size	-0.007*** (0.003)	0.237 (0.005)	-0.008*** (0.003)	0.235 (0.005)
Lev	0.130*** (0.017)	-0.141*** (0.033)	0.130*** (0.017)	-0.139*** (0.033)
Roa	0.174*** (0.046)	0.097 (0.090)	0.173*** (0.046)	0.092 (0.090)
Cfo	0.135*** (0.043)	-0.024 (0.084)	0.135*** (0.043)	-0.024 (0.084)
Growth	0.075*** (0.008)	-0.014 (0.015)	0.075*** (0.008)	-0.014 (0.015)
GI_input	0.448*** (0.071)	1.095*** (0.139)	0.447*** (0.071)	1.087*** (0.139)
Far	-0.005 (0.021)	-0.063 (0.041)	-0.005 (0.021)	-0.061 (0.041)
Lroa	0.107** (0.045)	-0.017 (0.088)	0.107** (0.045)	-0.018 (0.088)
Market	0.030*** (0.004)	-0.044*** (0.008)	0.030*** (0.004)	-0.043*** (0.008)
Share	0.036*** (0.014)	-0.045* (0.027)	0.037*** (0.014)	-0.042 (0.027)
Cons	0.714*** (0.091)	-5.110*** (0.177)	0.717*** (0.091)	-5.082*** (0.177)
Year	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes
N	16744	16744	16744	16744
R-Square	0.101	0.252	0.101	0.253

Depending on the above analysis, D&O insurance plays a positive role in promoting green innovation in enterprises. From columns (1) and (3) in Table 13, it can be seen that the regression coefficient of the influence of *DO* and *Time* on the volatility of the stock return rate within 3 years is positive at the significance level of 5%, so D&O insurance can improve the risk tolerance level of the enterprise. As can be seen from columns (2) and (4) in Table 13, under the significance level of 1%, the regression coefficient of the impact of the volatility of the stock return rate on the level of green innovation (*LnGI_all*) of the enterprise within 3 years is positive, indicating that the improvement of the level of risk commitment is helpful to promote the green innovation of the enterprise. Therefore, when the risk tolerance level of an enterprise is calculated by the volatility of the stock return within three years, D&O insurance does play its role in promoting green innovation by increasing the risk tolerance level. Similarly, as can be seen from Table 14, when the risk tolerance level of an enterprise

is measured by the volatility of the stock return within 5 years, D&O insurance can further promote the green innovation of an enterprise by improving the risk tolerance level of the enterprise.

To sum up, whether the volatility of the stock return within 3 years or the volatility of the stock return within 5 years is taken as the measurement standard of the enterprise's risk tolerance level, it is the risk-taking level that perform as a key element for directors to promote the green innovation of the enterprise.

Table 14. Test of the risk-taking level mechanism (measured by the stock return rate within 5 years)

Variable	(5)	(6)	(7)	(8)
	The stock returns 5 years	LnGI all	The stock returns 5 years	LnGI all
DO	0.022** (0.009)	0.166*** (0.019)		
Time			0.018*** (0.006)	0.130*** (0.013)
The stock returns 5 years		0.036** (0.016)		0.034** (0.016)
Size	-0.001 (0.002)	0.237 (0.005)	-0.001 (0.002)	0.235 (0.005)
Lev	0.125*** (0.016)	-0.141*** (0.033)	0.125*** (0.016)	-0.139*** (0.033)
Roa	0.143*** (0.044)	0.097 (0.090)	0.143*** (0.044)	0.092 (0.090)
Cfo	0.136*** (0.041)	-0.025 (0.084)	0.136*** (0.041)	-0.024 (0.084)
Growth	0.058*** (0.008)	-0.014 (0.015)	0.058*** (0.008)	-0.014 (0.015)
GI input	0.512*** (0.068)	1.091*** (0.139)	0.511*** (0.068)	1.083*** (0.139)
Far	-0.008 (0.020)	-0.063 (0.041)	-0.007 (0.020)	-0.061 (0.041)
Lroa	0.111** (0.043)	-0.018 (0.088)	0.111** (0.043)	-0.019 (0.088)
Market	0.034*** (0.004)	-0.045*** (0.008)	0.034*** (0.004)	-0.044*** (0.008)
Share	0.027** (0.013)	-0.044* (0.027)	0.027** (0.013)	-0.042 (0.027)
Cons	0.419*** (0.086)	-5.103*** (0.177)	0.424*** (0.086)	-5.075*** (0.176)
Year	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes
N	16744	16744	16744	16744
R-Square	0.083	0.252	0.083	0.253

6. Conclusion and Enlightenment

Taking China A-share listed companies from 2011 to 2020 as research samples, this paper empirically tests the impact of D&O insurance on corporate green innovation. The results show that D&O insurance can promote the green innovation of enterprises, which is less affected by other factors, and the longer the introduction time, the more obvious the effect. After applying Heckman's two-stage model to alleviate the endogenous problem of enterprises' subjective choices, changing the measurement method of the explained variables, and removing the robustness test of samples with weak relevance to green innovation, the estimation results are consistent with the main regression results, and the conclusion is still valid. The further study found that D&O insurance has a significant and relatively stable promoting effect on the invention type green innovation with higher innovation quality and the utility model type green innovation with lower innovation quality; the promotion

effect of D&O insurance on green innovation is more obvious in large-scale enterprises. The level of risk tolerance is a vital factor for directors to promote green innovation.

Based on the previous research and analysis, this paper puts forward the following three relevant suggestions for the enterprise itself, regulatory agencies, and government departments. First of all, enterprises should seize the opportunity of green transformation, establish a strategic perspective of sustainable development, actively introduce and continuously purchase D&O insurance. Through these measures, they are supposed to strengthen green innovation activities, promote the establishment of green innovation concept of managers, and promote the cultivation of green innovation awareness of research and development personnel. Secondly, considering that the legal environment is still not perfect, the regulatory authority can issue supporting regulations on D&O insurance to protect small and medium-sized enterprises and allow D&O insurance to play a better role. Finally, government departments can consider granting green subsidies to small and medium-sized enterprises so that they are competent to have the sufficient cash flow to sustain the purchase of D&O insurance and improve the level of green innovation of enterprises.

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