D&O insurance, technology independent directors, and R&D investment

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ABSTRACT

This study examines the effect of technology independent directors on firm R&D investment and investigated the influence and mechanism of directors' and officers' liability insurance[1] on the above effect. We find that technology independent directors positively affect R&D investment, and purchasing D&O insurance can significantly enhance this effect by improving the diligence of technology independent directors. The moderating effect of D&O insurance is more pronounced for private firms and younger technology independent directors. These results suggest that D&O insurance positively motivates independent directors to serve their fiduciary duties and provides new empirical evidence on the governance effects of D&O insurance in emerging markets and independent director groups.

1. Introduction

R&D is the key link of firm innovation, which can bring continuous competitive advantage to firms. As outside directors, independent directors introduce new knowledge, skills and resources to the board of directors. Specific industry knowledge is crucial for strategic decision making (Coles, Daniel, & Naveen, 2008; Linck, Netter, & Yang, 2008). We focus on the technology independent directors and examine the impact of their technical experience on R&D investment. The reason is that one of the functions of independent directors is to provide professional consultation for firm strategy by using their expertise. According to the upper echelons theory, the characteristics of directors affect the strategic decision making of firms. The mindset and behavior pattern of technology independent directors are mostly related to technical activities. Therefore, when participating in firm decision making, technology independent directors will pay more attention to the technological progress and are more likely to lead the strategies to R&D innovation. Meanwhile, according to the resource dependence theory, technology independent directors provide more expertise and experience, forming scarce resources for the firm. It is helpful for the board of directors to find more investment opportunities and promote the R&D investment. However, studies focusing on the impact of technology independent directors on R&D investment are still limited.

In addition, R&D, as an investment activity of firm, is characterized by a long payback period, high investment cost, and high risk. Directors' risk tolerance will directly affect the R&D investment. In China, independent directors, like other inside directors, bear the same responsibility for the decision making, but there is a wide gap between them in the salary level. The asymmetry of risk-benefit and the excessive risk[2] of serving fiduciary duties lead to the conservative behavior of independent directors, with obvious characteristics of risk-averse (Asthana & Balsam, 2009; Fahlenbrach, Low, & Stulz, 2010). The inherent risk-averse characteristics of technology independent directors may lead to their inability to serve fiduciary duties effectively. Under such circumstances, D&O insurance will be of great help. A firm purchases D&O insurance as a kind of professional liability insurance. When directors and officers are held personally liable for negligence or misconduct in decisions and actions, the insurance firm will bear the related civil compensation costs. D&O insurance is more common in developed countries, but the insured rate in China's A-share market is still low, less than 16% as of 2020. The rules for independent directors of listed firms issued by the CSRC (China Securities Regulatory Commission) on January 5th, 2022, emphasized that listed firms can establish a necessary liability insurance system for independent directors to

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[1] We will use "D&O insurance" for "directors' and officers' liability insurance" throughout the article.

[2] In 2021, the financial fraud case of Kangmei Pharmaceutical was settled. All five independent directors were sentenced to bear 5% or 10% joint liability for failing to perform their duty of diligence. The amount of penalty was up to hundreds of millions. Compared with the remuneration of independent directors in China, it was "astronomical". The case of Kangmei Pharmaceutical has a deterrent effect on the group of independent directors, and reminds independent directors to further protect their rights and interests.

mitigate the risks of serving their fiduciary duties.

D&O insurance aims to improve the risk-taking level of directors and officers, encourage them to actively serve their fiduciary duties, and introduce insurance firms as external supervisors to improve corporate governance. Most of the existing literature has examined the governance role of D&O insurance as an independent internal governance mechanism, mainly from the perspectives of accounting quality (Weng, Chen, & Chi, 2017; Yuan, Sun, & Cao, 2016), corporate risk-taking level (Hwang & Kim, 2018), audit fees (Chung & Wynn, 2014; O'Sullivan, 2009), investment and financing behavior (Chen, Li, & Zou, 2016; Li & Liao, 2014), and corporate innovation (Wang, Zhang, Huang, & Zhang, 2020). However, rather than inferring the governance implications of D&O insurance, a more direct approach would be to examine how D&O insurance directly affects the behavior of directors and officers (Jia & Tang, 2018). Yet, little literature has examined the effect of D&O insurance on independent directors. Therefore, we choose technology independent directors as the beneficiary to explore the effects of D&O insurance on the relationship between technology independent directors and R&D investment.

In summary, this paper examines the impact of D&O insurance on the performance of technology independent directors and the mechanism of its effect by using the data of Chinese A-share listed firms from 2008 to 2020. Among them, the performance of technology independent directors is measured by firm R&D investment. The study finds that employing technology independent directors is conducive to promoting the R&D investment, while purchasing D&O insurance can strengthen the promotion effect of technology independent directors on R&D investment. The mechanism is that D&O insurance improves the risk-taking level of technology independent directors, and enhances their diligence of serving fiduciary duties, thus producing incentive effects.

To address potential endogeneity concerns such as omitted variables, reverse causality, sample bias, and sample self-selection, we adopt IV approach, lagged effect, PSM approach, treatment effect models, and placebo tests. Consistent research results are still obtained. Through the heterogeneity analysis, we find that D&O insurance's incentive effects are more pronounced in private firms than in state-owned firms. Moreover, the incentive effect of D&O insurance on younger technology independent directors is more pronounced than that of older ones. In the additional analysis, the incentive effect of D&O insurance can be expressed as independent directors are more willing to issue diligence opinions and bolder to issue dissenting opinions, i.e., an increase in the diligence of serving fiduciary duties.

The marginal contributions of our study are as followings: first, the inclusion of independent directors in the beneficiary subjects framework of D&O insurance. This research examines the impact of D&O insurance on the performance of technology independent directors, providing a new perspective for studying the governance effects of D&O insurance. Second, previous literature has focused on the incentive effect of remuneration and reputation on independent directors, while this paper verifies the incentive effect of D&O insurance on independent directors and expands the research on the incentive mechanism of independent directors. Finally, considering the unique situation of independent directors in China, D&O insurance significantly reduces the litigation risk of independent directors, and enhances their performance effectiveness, which provides empirical evidence for regulators to improve the independent director system.

The remainder of the paper is organized as follows. Section 2 summarizes the literature review and develops the hypotheses. Section 3 introduces sample construction and data. Section 4 presents the empirical results. Section 5 presents the heterogeneity analysis results. Section 6 discusses additional analysis. Section 7 concludes our study.

2. Literature review and research hypothesis

2.1. Directors' characteristics and R&D investment

As the core body of firm decision making, the board of directors plays an important advisory and supervisory role in R&D investment. A number of studies have found that the proportion of independent directors (Balsmeier, Fleming, & Manso, 2016; Faleye, Hoitash, & Hoitash, 2011), age of directors (Atallah, Fuentes, & Panasian, 2020), gender of directors (Attia, Yousfi, Loukil, & Omri, 2021; Chen, Ni, & Tong, 2016), education level of directors (Attia et al., 2021; Midavaine, Dolfsma, & Aalbers, 2016), CEO tenure (Azzam & Alhababsah, 2022), technical experience of directors (Hartley, 2011; Li, Liu, & Xie, 2019), political connections of directors (Shi, Xu, & Zhang, 2018) and other board characteristics have an important impact on firms' R&D decisions. Among them, technical experience is a key feature. The professionalism and high complexity of R&D require the assistance of technical experts to ensure the output efficiency of R&D investment. Independent directors as external experts, their technical expertise plays an positive role in the R&D decision making. Li et al. (2019) find that technology directors have a positive effect on firm R&D investment, patents applied and patents granted. Meanwhile, compared with technology executive directors, technology independent directors have a stronger effect on patents granted. Li, Li, and Xie (2020) measure technology independent directors by whether the technical expertise of an independent director is relevant to the operational field of the firm, and find that technology independent directors play a role in improving firm's innovation by supporting further research in the current field. At present, the literature on the impact of technology independent directors on firm R&D investment is still limited.

2.2. The corporate governance role of D&O insurance

There are two opposing views on the role of D&O insurance in corporate governance. One is incentive view, which believes that D&O insurance has external monitoring and incentive function, thus contributing to improve corporate governance. The reason is that, first, the risk hedging mechanism of D&O insurance can transfer the risk of claims caused by directors' and officers' negligence to the insurance firm, alleviates their performance concerns, potential risk aversion, and other agency problems, thus motivating them to serve their fiduciary duties (Core, 1997). Also, D&O insurance can attract and retain excellent executives (Romano, 1991). Second, D&O insurance introduces insurance firms into an external monitoring system (O'Sullivan, 1997), restrains managers' behavior, and alleviates agency conflicts (Core, 1997). Finally, D&O insurance helps executives to focus their decisions on the future success drivers of the firm rather than on their personal gains and losses, thus improving the quality of their decisions (Jia & Liang, 2013). Some literature supports the above views. For example, Hwang and Kim (2018) find that firms with D&O insurance coverage increase their firm value by seizing better growth opportunities. Wang et al. (2020) also find that D&O insurance is significantly and positively associated with innovation, suggesting that D&O insurance increase managers' tolerance for failure.

Another is self-interest view, which believes that the "bottom line" effect of D&O insurance reduces the cost of self-interest for directors and officers. D&O insurance may cause a moral hazard and stimulate their opportunistic behavior, which harms corporate governance (Lin, Officer, & Zou, 2011). Conclusions of some literature also support the above views, such as lower sensitivity of directors' compensation to firm performance and more severe agency problems for executives after

purchasing D&O insurance (Wang & Chen, 2016); worse accounting conservatism (Chung & Wynn, 2008), more earning management (Jia & Liang, 2013), higher probability of financial restatement (Lin, Officer, Wang, & Zou, 2013); increased cost of equity (Chen, Li, & Zou, 2016), more aggressive investment decisions (Chiang & Chang, 2022; Li & Liao, 2014), and more serious corporate tax avoidance (Zeng, 2017).

Most studies consider D&O insurance as an independent internal governance mechanism and examine its indirect impact on management decisions separately (Jia & Liang, 2013). Some literature also examine the information conveyed by the purchase of D&O insurance from an external stakeholder's perspective. Bhagat, Brickley, and Coles (1987) find positive and slight market reactions to the announcement of D&O insurance purchases in a sample of 11 New York-based firms. Lin et al. (2013) identify that D&O insurance is associated with higher loan spread, because it increases credit risks through moral hazard and information asymmetry. Chen, Li, and Zou (2016) reveal a positive relationship between D&O insurance and the β coefficient of the firm's stock. Liao, Tang, and Lee (2017) find that the relationship between firm credit rating and D&O insurance is affected by the match between the insured amount and the corporate traits. Only when the two match, purchasing D&O insurance is conducive to improving the firm credit rating. The research of O'Sullivan (2009) and Chung and Wynn (2014) show that D&O insurance affect the auditors' risk expectations and audit pricing, thus increasing audit fees.

2.3. D&O insurance, technology independent directors, and firm R&D investment

The original intention of purchasing D&O insurance for firms is to reduce the litigation risk of directors and officers. Its direct effect should be on the behavior of directors and officers. Therefore, in examining the governance role of D&O insurance, a more direct approach should be to explore the impact of D&O insurance on the behavior of directors and officers. Although independent directors are the important beneficiaries of D&O insurance and an essential element of corporate governance, the existing literature still knows little about how D&O insurance affects the behavior of independent directors. Jia and Tang (2018) first focus on the impact of D&O insurance on the behavior of independent directors. They measured the behavior of independent directors in terms of board meeting attendance, diligence in issuing opinion reports, and the number of board seats. They find that D&O insurance introduced moral hazard into the board of directors, resulting in lower board meeting attendance, less diligence in issuing opinion reports, and more inclination to take up additional positions in other firms. Li, Yang, and Zhu (2022) support the incentive view of D&O insurance by comparing the votes of independent directors and other directors of the same firm for the identical proposal and find that insured independent directors are more likely to "say no". However, most of the literature focuses on the fact that D&O insurance improves the level of risk-taking by directors and officers (Boyer & Tennyson, 2015; Lin et al., 2013; Wang et al., 2020) and does not further concentrate on the group of independent directors.

According to the upper echelons theory, directors and executives are the main body of strategic decision making, and their demographic characteristics will affect the firm's decision making. The characteristics of independent directors will also influence their performance. The mindsets and behavioral traits of technology independent directors with experience in R&D, design, etc., are often related to technological activities. As a result, technology independent directors are more likely to direct the firm's strategy toward R&D and innovation. In addition, the expertise, skills, and experience possessed by technology independent directors form a firm-specific resource. According to the resource dependence theory, employing technology independent directors will facilitate the identification of innovation opportunities, and promote the R&D investment. Existing studies on technology independent directors are also linked mainly to R&D investment and innovation in firms (Li

et al., 2020; Liu & Zhou, 2020). Therefore, we state our hypothesis as follows:

H1. The presence of technology independent directors is positively associated with firm R&D investments.

Given the high-risk characteristics of R&D activities and the risk-averse features of independent directors, the introduction of D&O insurance is bound to impact the relationship between them significantly. Although there is still a dispute about the corporate governance role of D&O insurance, the common basis of both controversies is that D&O insurance will improve the risk-taking level of directors and officers, which has been confirmed by existing studies (Core, 1997). The increase of risk-taking level can fundamentally enhance independent directors' independence, making them bolder in issuing opinions and participating in the firm's decision making. D&O insurance is conducive to reducing the litigation risk of independent directors and the asymmetry of risk-benefit, solving the worries of independent directors, and stimulating their motivation, thus serving as an incentive.

The reason that the self-interest view of D&O insurance hardly works for independent directors is that the fundamental motivation of the self-interest view is profit-driven, which triggers opportunistic behavior. Whereas the source of economic benefits that independent directors receive from the firm in China is their compensation, this compensation level is insufficient to induce active opportunistic behavior of independent directors. As for whether independent directors will collaborate with insiders and engage in passive opportunistic behavior due to the pressure of re-election? It's not practical in China. First, as external directors, technology independent directors represent the interests of small and medium-sized shareholders and play a supervisory role in addition to their advisory role. Second, the compensation of D&O insurance is payable on the premise that the directors and officers have fulfilled their duty of diligence. Therefore, the independent directors' conspiracy with insiders is bound to violate the duty of diligence, and D&O insurance cannot transfer their risks. In this case, the risks of the independent directors are inevitably much greater than the benefits. Consequently, we argue that the incentive effect of D&O insurance on technology independent directors will outweigh the self-interest effect from a rational perspective and proposes the following hypothesis:

H2. Technology independent directors' positive impact on R&D investment is more pronounced for firms with D&O insurance coverage than for firms without D&O insurance coverage.

3. Sample construction and data

3.1. Sample selection and data sources

We select the data of Chinese A-share listed firms from 2008 to 2020 as the primary research sample. China introduced D&O insurance for the first time in 2002, the proportion of D&O insurance coverage was low in the early period. In addition, China began to implement new accounting standards in 2007. In order to avoid the impact of accounting standard changes on R&D investment, we set the starting point of the sample period as 2008. Except for the data on D&O insurance collected manually, all other corporate governance and financial data are obtained from the China Stock Market & Accounting Research (CSMAR) database. We exclude the observations in financial industry, and observations with missing data for the interesting and control variables. Finally, our sample includes 21,594 firm-year observations for 3136 firms.

3.2. Selection of variables

3.2.1. D&O insurance

The data of D&O insurance used in our study is obtained by downloading the annual reports of firms, board of directors' announcements, and shareholders' meeting announcements in bulk through Python on

cninfo.com.cn and capturing the keywords of D&O insurance manually. Suppose a firm proposed and passed a bill to purchase D&O insurance in its annual report, board of directors' announcement or shareholders' meeting announcement in a certain year. In that case, it is considered that the firm purchased D&O insurance in that year and renewed it in subsequent years as well. We follow the practice of most literature on D&O insurance (Jia & Tang, 2018; Li et al., 2022) and set a dummy variable *Ins* to indicate whether the firm purchased D&O insurance or not.

3.2.2. Technology independent directors

Referring to the research of Li et al. (2019) and Liu and Zhou (2020), we define technology independent directors as directors with working or research experience in production, design, science, engineering, and/or technology. The professional background data come from the resumes of independent directors in the CSMAR database. In order to reduce the missing data as much as possible, when the resume is missing, we supplement the data by checking the firms' annual reports, and official websites. We then created a key independent variable, *Tech*, which is equal to 1 if the firm i has at least one director with technical background in year t, and 0 otherwise.

3.2.3. Control variables

Referring to the prior literature (Li et al., 2019; Li et al., 2020; Liu & Zhou, 2020), we control some corporate governance variables and firm-level independent directors' characteristic variables, such as assets (*Lnasset*), leverage (*Lev*), firm age (*Age*), government subsidy (*Subsidy*), shareholding concentration (*Top1*), shareholding balance (*Sba*), board size (*Bsize*), proportion of independent directors (*Ind*), shareholding ratio of managers (*Mgt*), growth rate of sales (*Growth*), return on assets (*ROA*), chair-CEO duality (*Power*), the age of independent directors (*Indage*), the gender of independent directors (*Indgender*) and the board seats number of independent directors (*Indsum*). In addition, we include year and industry fixed effects to account for variation in R&D investment that may be driven by year and unobserved industry heterogeneity. Appendix A provides detailed definitions of all variables used in our analysis.

3.3. Model specification

We mainly consider the effect of technology independent directors on firm R&D investment, and impact of D&O insurance on the relationship between them. *RD_ratio* is considered as the dependent variable, *Tech* is regarded as the independent variables, and *Ins* is used as a moderating variable. Since the firm may not sign a contract with the insurance firm in the year in which the purchase bill of D&O insurance is passed, so *Ins* is treated in the model with a one-period lag. We control the industry fixed effect and the year fixed effect simultaneously. The basic model is set as follows:

Table 1
Univariate statistics.

Panel A: Partitioned by technology independent directors

Variable	Tech = 1 (n = 8997)		Tech = 0 (n = 12,597)		Difference
	Mean	SD	Mean	SD	
RD_ratio	1.820	1.859	1.553	1.943	0.267***
Patents	0.627	1.434	0.475	1.295	0.152***
Ins	0.052	0.223	0.072	0.258	−0.019***
Soe	0.381	0.486	0.432	0.495	−0.050***
Local	0.454	0.497	0.454	0.501	0.000
Lnasset	22.180	1.281	22.222	1.256	−0.042**
Lev	0.423	0.202	0.445	0.203	−0.022***
Age	2.791	0.351	2.881	0.326	−0.090***
Subsidy	0.004	0.006	0.004	0.006	0.000
Top1	34.638	14.537	34.730	14.639	−0.092
Sba	0.903	0.767	0.845	0.745	0.058***
Bsize	2.159	0.194	2.123	0.199	0.036***
Ind	0.374	0.053	0.374	0.053	0.000
Mgt	0.136	0.197	0.095	0.171	0.041***
Growth	0.204	0.449	0.179	0.466	0.025***
ROA	0.045	0.053	0.042	0.057	0.003***
Power	0.258	0.438	0.240	0.427	0.019***

Panel B: Partitioned by D&O insurance

Variable	Tech = 1 (n = 8997)		Difference	Tech = 0 (n = 12,597)		Difference
	Ins = 1 (n = 470)	Ins = 0 (n = 8527)		Ins = 1 (n = 908)	Ins = 0 (n = 11,689)	
RD_ratio	1.267	1.850	−0.584***	1.023	1.594	−0.571***
Patents	0.833	0.616	0.217***	0.526	0.471	0.055
Soe	0.747	0.361	0.386***	0.673	0.413	0.260***
Lnasset	23.366	22.115	1.251***	23.194	22.147	1.048***
Now	6.194	6.169	0.025**	6.228	6.156	0.072***
Ndili	3.132	3.054	0.078	3.331	3.008	0.323***
Neg	0.024	0.009	0.015***	0.015	0.010	0.005

Panel A provides univariate statistics of main variables in our sample partitioned by whether a firm with technology independent directors. Panel B provides univariate statistics of key variables further partitioned by whether a firm with D&O insurance coverage. All of the continuous variables are winsorized at the top and bottom 1% level. Appendix A provides detailed variable definitions.

3.4. Summary statistics

Panel A of Table 1 reports the univariate statistics of the main variables partitioned by whether the firm with technology independent directors. *RD_ratio* of firms with technology independent directors (1.820) is significantly higher than that of firms without technology independent directors (1.553), indicating that without considering the control

$$RD\_ratio_{i,t} = \alpha_0 + \alpha_1 Tech_{i,t} + \alpha_2 Lnasset_{i,t} + \alpha_3 Lev_{i,t} + \alpha_4 Growth_{i,t} + \alpha_5 ROA_{i,t} + \alpha_6 Subsidy_{i,t}$$
$$+ \alpha_7 Age_{i,t} + \alpha_8 Top1_{i,t} + \alpha_9 Sba_{i,t} + \alpha_{10} Bsize_{i,t} + \alpha_{11} Ind_{i,t} + \alpha_{12} Mgt_{i,t} + \alpha_{13} Power_{i,t}$$
$$+ \alpha_{14} Soe_{i,t} + \sum Indu + \sum Year + \varepsilon_{i,t} \tag{1}$$

$$RD\_ratio_{i,t} = \beta_0 + \beta_1 Tech_{i,t} + \beta_2 Tech_{i,t} \times Ins_{i,t-1} + \beta_3 Ins_{i,t-1} + \beta_4 Lnasset_{i,t} + \beta_5 Lev_{i,t} + \beta_6 Growth_{i,t}$$
$$+ \beta_7 ROA_{i,t} + \beta_8 Subsidy_{i,t} + \beta_9 Age_{i,t} + \beta_{10} Top1_{i,t} + \beta_{11} Sba_{i,t} + \beta_{12} Bsize_{i,t} + \beta_{13} Ind_{i,t}$$
$$+ \beta_{14} Mgt_{i,t} + \beta_{15} Power_{i,t} + \beta_{16} Soe_{i,t} + \sum Indu + \sum Year + \varepsilon_{i,t} \tag{2}$$

variables, employing technology independent directors improves the R&D investment, which is consistent with the expectation of Hypothesis 1. *Patents* of firms with technology independent directors (0.627) is also significantly higher than that of firms without technology independent directors (0.475). The mean value of *Ins* are 0.052 and 0.072, suggesting that the ratio of D&O insurance coverage in China is significantly lower than that in Europe and the United States.

Panel B of Table 1 further reports the univariate statistics of key variables partitioned by whether the firm with technology independent directors and whether the firm with D&O insurance coverage. Among firms with technology independent directors, *RD_ratio* of firms with D&O insurance coverage (1.267) is significantly lower than that of firms without D&O insurance coverage (1.850), but *Patents* of firms with D&O insurance coverage (0.833) is significantly higher than that of firms without D&O insurance coverage (0.616). The reason is that most of the firms that purchased D&O insurance are state-owned firms (0.747 versus 0.361) with more assets (23.366 versus 22.115). However, *RD_ratio* is the ratio of R&D investment to total assets. When total assets are higher, RD_ratio is necessarily lower. The descriptive statistics is consistent with the research of Wang et al. (2020). In addition, independent directors of firms with D&O insurance coverage are more active in serving their fiduciary duties, issue independent opinions with more words (6.194 versus 6.169), and are more likely to say "No" to the board

of directors (0.024 versus 0.009). These can preliminarily show that D&O insurance affects the relationship between technology independent directors and R&D investment by improving the performance of technology independent directors. The univariate statistics for firms without technology independent directors are similar.

4. Empirical results

4.1. Baseline regression results

We estimate the impact of technology independent directors on R&D investment using model (1) and the effect of D&O insurance on them using model (2). From columns (1) of Table 2, it can be seen that the regression coefficient on *Tech* is significantly positive, indicating that the employment of technology independent directors by listed firms can significantly increase the level of R&D investment, which is consistent with the findings of existing studies (Liu & Zhou, 2020), and also confirms hypothesis H1. Interaction terms' coefficient on *Tech*Ins* in columns (2) of Table 2 is positive and significant at the 5% level, indicating that D&O insurance has an incentive effect on technology independent directors, thus increasing the promotion of R&D investment by technology independent directors, and hypothesis H2 is supported. Regarding control variables, *ROA, Subsidy, Mgt* and *Power* are significantly and positively correlated with R&D investment, while *Lnasset, Lev, Growth, Age* and *Top1* are significantly and negatively correlated with R&D investment.

Column (2) of Table 2 basically supports hypothesis H2. To further calculate the magnitude of the interaction between D&O insurance and technology independent directors. Following the procedures of Wiersema and Bowen (2009), the marginal effect of technology independent directors on R&D investment is calculated concerning whether the firm purchases D&O insurance, and the results are presented in Table 3 and Fig. 1. In Table 3, the marginal effect of technology independent directors of firms with D&O insurance coverage (b = 0.319, t = 3.71) is significantly stronger than that of firms without D&O insurance coverage (b = 0.095, t = 4.15), indicates that D&O insurance dramatically enhances the effect of technology independent directors on R&D investment. In Fig. 1, for firms with D&O insurance coverage, R&D investment increased by 20.28% when technology independent directors varied from zero to one; for firms without D&O insurance coverage, R&D investment increased by 5.85% when technology independent directors varied from zero to one. Therefore, the promotion of R&D investment by technology independent directors of firms with D&O insurance coverage is stronger compared to firms without D&O insurance coverage, further supporting hypothesis H2.

4.2. Endogeneity tests

The above results may have endogeneity problems, such as the reverse causality problem of employing technology independent directors due to R&D needs, the sample self-selection problem of purchasing D&O insurance in response to the high risk of R&D, and the possible existence of omitted variables. To address the endogeneity concern, we conduct a battery of tests.

4.2.1. Two-stage instrumental variable approach

To mitigate the potential concern of omitted variables bias, we introduce *University* and *Ins_province* as instrumental variables for *Tech* and *Ins*, respectively. Universities are one of the main sources of

Table 2
D&O insurance, technology independent directors and R&D investment.

	RD_ratio	
	(1)	(2)
Tech	0.106***	0.095***
	(4.81)	(4.15)
Tech*Ins		0.224**
		(2.52)
Ins		−0.050
		(−1.10)
Lnasset	−0.074***	−0.075***
	(−6.66)	(−6.71)
Lev	−0.153**	−0.153**
	(−2.23)	(−2.23)
Growth	−0.036*	−0.035*
	(−1.79)	(−1.73)
ROA	4.050***	4.055***
	(16.14)	(16.16)
Subsidy	42.531***	42.496***
	(15.97)	(15.95)
Age	−0.471***	−0.471***
	(−12.46)	(−12.48)
Top1	−0.002**	−0.002**
	(−2.02)	(−2.05)
Sba	0.013	0.012
	(0.62)	(0.56)
Bsize	−0.059	−0.061
	(−0.86)	(−0.89)
Ind	0.054	0.051
	(0.24)	(0.22)
Mgt	0.625***	0.628***
	(8.33)	(8.37)
Power	0.092***	0.092***
	(3.48)	(3.47)
Soe	0.013	0.011
	(0.47)	(0.40)
CONS	2.060 ***	2.092 ***
	(5.52)	(7.16)
Year fixed effect	Yes	Yes
Industry fixed effect	Yes	Yes
Adj R2	0.386	0.386
N	21,594	21,594

This table presents the baseline regression results on the relationship between technology independent directors and R&D investment (column (1)) and the effect of D&O insurance on them (column (2)). Two-tailed t-statistics are reported in parentheses. *, **, ***, represent statistical significance at 0.1, 0.05, and 0.01 levels, respectively. Appendix A provides detailed variable definitions.

Table 3
Marginal effects of technology independent directors on firm R&D investment.

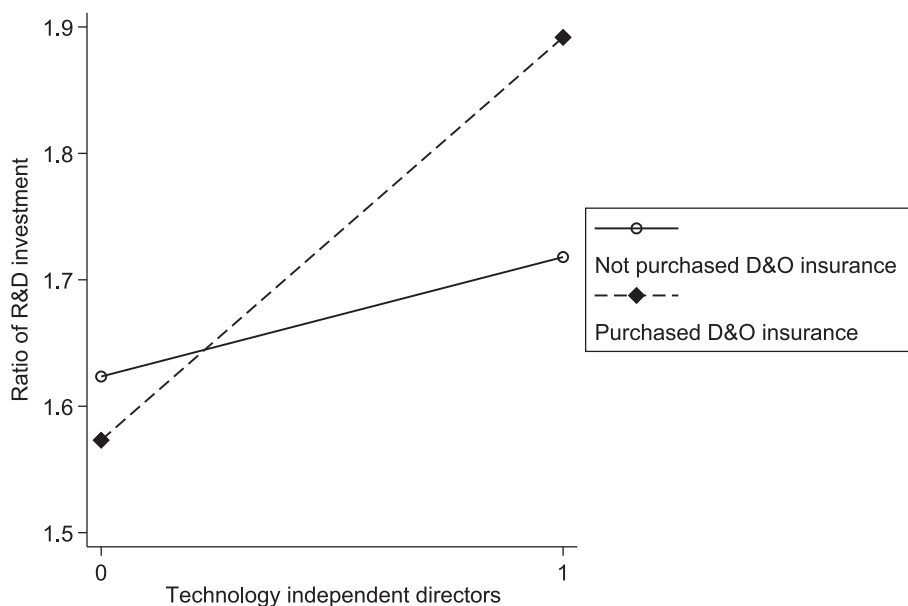| D&O insurance	Marginal effect	T-value
Not purchased	0.095	4.15
Already purchased	0.319	3.71

Fig. 1. The interactive effect of D&O insurance and technology independent directors.
The figure presents the interactive effect of D&O insurance and technology independent director on the ratio of R&D investment.

independent directors in China. The greater the number of science, technology, agriculture and medicine universities in the province where the firm is located, the richer the technical talents in the region are, and the more likely the firm is to employ technology independent directors. The higher the ratio of D&O insurance coverage in the province where the firm is located, the higher the recognition of D&O insurance by firms in the same region, and the more likely the firm is to purchase D&O insurance. However, there is no evidence that *University* and *Ins_province* directly affect the firm's R&D investment. Therefore, we believe that our instrumental variables satisfy both relevance and exclusivity.

We adopt the two-stage IV approach, that is, in the first stage, *Tech* and *Ins* are taken as the dependent variable respectively, while *University* and *Ins_province* are taken as independent variable accordingly. Other control variables are considered for regression. We also control for industry and year fixed effects. The regression results are shown in column (1) and column (2) of Table 4. The coefficients on *University* and *Ins_province* are significantly positive at the 1% level, respectively. The minimum eigenvalue statistic are 31.798 and 14.646, supporting the validity of our instruments. Then, the fitted value of *Tech* and *Ins* obtained from the first stage regression are brought into the second stage, i. e., model (1) and model (2) for regression as an exogenous variable. The regression results are shown in column (3) and column (4) of Table 4. The regression coefficient on *Tech(IV)* and *Tech(IV)*Ins(IV)* are still significantly positive, indicating that the our results are not driven by omitted variables.

4.2.2. Lagged effects

Firms may employ technology independent directors due to the need for technological innovation, there may be reverse causality in our study. We lag the independent variables by one year and two years in separate regressions to solve this endogenous problem. Table 5 shows the regression results, the coefficients on *Tech_1* and *Tech_2* are both significantly positive at the 1% level, suggesting that technology independent directors still have a strong and positive impact on firm R&D investment after controlling for potential reverse causality concern.

4.2.3. Propensity score matching approach

From the univariate statistics in Panel B of Table 1, the characteristics between firm with D&O insurance or not are significant different. In order to avoid sample selection bias and potentially misleading

conclusions, we use the propensity score matching (PSM) approach here. A sample of firms with D&O insurance coverage is matched with a control group of firms that are very close in firm characteristics but without D&O insurance coverage. And model (2) is re-regressed with the newly matched sample. The specific matching process is as follows: firstly, probit regression is conducted with assets, leverage, growth rate of sales, return on assets, firm age, shareholding balance, proportion of independent directors, shareholding ratio of managers, chair-CEO duality, and state ownership as matching variables to obtain the propensity score (PS) value of each observation; then one-to-one nearest neighbor matching without replacement is used in the control group sample that without D&O insurance coverage. The sample deviations between the treatment and control groups after matching are less than 5% except for *Mgt*, and the T-values become no longer significant, indicating that the sample satisfy the conditions of the equilibrium hypothesis from an overall perspective. The regression results in Table 6 show that the interaction term coefficients are still significantly positive at the 1% level, which are consistent with the previous findings.

4.2.4. Treatment effect model

Firms that aim to do more R&D might have more tendency to purchase D&O insurance in order to reduce the risk of litigation. Therefore, the previous results may have self-selection problem. We use the treatment effect model to further control it. In the first stage, a probit model of factors influencing firms' purchase of D&O insurance is established. The ratio of D&O insurance coverage in the province where the firm is located is used as instrumental variables to calculate the Inverse Mills ratio (IMR), which is then added as control variables in the model (2) for the second stage regression. As can be seen in column (1) and column (2) of Table 7, the coefficients on the interaction term is still significantly positive at the level of 5%, which is consistent with the previous findings. However, the coefficient of IMR is significant, indicating that the self-selection of samples does exist.

4.2.5. Technology independent directors vs. non-technology independent directors

In order to demonstrate the unique effect of D&O insurance on R&D investment via technology independent directors rather than non-technology independent directors, we use a placebo test to randomly assign whether firms with technology independent directors and repeats

Table 4
Endogeneity test1: Instrumental variable results.

	First stage		Second stage	
	Tech	*Ins*	*RD_ratio*	
	(1)	(2)	(3)	(4)
University	0.040***			
	(5.48)			
Tech(IV)			5.406***	2.307***
			(4.75)	(3.48)
Ins_province		1.041***		
		(22.82)		
*Tech(IV)*Ins(IV)*				4.112**
				(1.96)
Ins(IV)				2.945***
				(3.45)
Lnasset	0.003	0.031***	−0.091***	−0.225***
	(0.86)	(14.82)	(−4.28)	(−10.14)
Lev	−0.064***	0.005	0.189	0.035
	(−3.03)	(0.50)	(1.25)	(0.32)
Growth	0.005	−0.004	−0.065	−0.016
	(0.76)	(−1.09)	(−1.48)	(−0.51)
ROA	−0.018	−0.104***	4.087***	4.599***
	(−0.28)	(−3.36)	(9.68)	(14.10)
Subsidy	1.162**	0.318	36.648***	38.519***
	(2.08)	(1.32)	(9.13)	(12.20)
Age	−0.099***	0.047***	0.065	−0.413***
	(−8.61)	(9.48)	(0.48)	(−5.22)
Top1	0.001*	−0.000	−0.005**	−0.004**
	(1.64)	(−0.36)	(−2.32)	(−2.50)
Sba	0.017***	0.009***	−0.078*	−0.089***
	(2.78)	(3.40)	(−1.79)	(−2.76)
Bsize	0.364***	0.007	−1.978***	−0.989***
	(18.24)	(0.70)	(−4.60)	(−4.02)
Ind	0.598***	0.119***	−3.048***	−1.960***
	(8.43)	(3.48)	(−3.83)	(−3.81)
Mgt	0.112***	−0.038***	0.004	0.488***
	(5.03)	(−5.83)	(0.02)	(3.98)
Power	0.011	−0.008***	0.033	0.086**
	(1.36)	(−2.62)	(0.64)	(2.43)
Soe	−0.013*	0.027***	0.098*	−0.088**
	(−1.65)	(6.45)	(1.83)	(−2.20)
CONS	−0.644***	−0.883***	4.705***	7.146***
	(−6.82)	(−16.14)	(5.94)	(10.21)
Year fixed effect	Yes	Yes	Yes	Yes
Industry fixed effect	Yes	Yes	Yes	Yes
Adj R2	0.126	0.097	.	.
N	21,594	21,594	21,594	21,594
Minimum eigenvalue statistic	31.798	14.646		

This table reports endogeneity test results using two-stage IV approach. Column (1) reports the first stage regression results showing the relation between *University* and *Tech*, and the fitted value is used in place of *Tech* in column (3) and column (4). Column (2) reports the first stage regression results showing the relation between *Ins_province* and *Ins*, and the fitted value is used in place of *Ins* in column (4). Column (3) repeat the baseline model (1) by replacing *Tech* with its fitted values computed in the first stage. Column (4) repeat the baseline model (2) by replacing *Tech* and *Ins* with their fitted values computed in the first stage. Two-tailed t-statistics are reported in parentheses. *, **, ***, represent statistical significance at 0.1, 0.05, and 0.01 levels, respectively. Appendix A provides detailed variable definitions.

the regression of model (2) 1000 times. Coefficients and T-values of the interaction term of the regression results, are shown in Table 8 and Fig. 2. As can be seen from Table 8, the percentage of the 1000 regression results with significant coefficients is relatively small. And the T-values in Fig. 2 are concentrated around 0, implying that the virtual treatment effect does not exist. The effect of D&O insurance on R&D investment is indeed realized through technology independent directors.

4.2.6. With D&O insurance coverage vs. without D&O insurance coverage

To further test the moderating effect of D&O insurance, we use a placebo test to randomly assign whether firms purchase D&O insurance

Table 5
Endogeneity test2: Lagged effects.

	RD_ratio	
	(1)	(2)
Tech_1	0.116***	
	(4.96)	
Tech_2		0.131***
		(5.04)
Lnasset	−0.060***	−0.045***
	(−4.87)	(−3.27)
Lev	−0.144*	−0.142*
	(−1.90)	(−1.68)
Growth	−0.048**	−0.056**
	(−2.13)	(−2.28)
ROA	4.028***	3.905***
	(14.73)	(12.94)
Subsidy	47.255***	52.598***
	(15.61)	(15.15)
Age	−0.452***	−0.419***
	(−10.71)	(−8.68)
Top1	−0.003**	−0.004***
	(−2.43)	(−2.80)
Sba	−0.011	−0.042*
	(−0.51)	(−1.69)
Bsize	−0.032	−0.011
	(−0.44)	(−0.14)
Ind	0.034	0.116
	(0.14)	(0.42)
Mgt	0.604***	0.63***
	(6.98)	(6.20)
Power	0.092***	0.108***
	(3.15)	(3.30)
Soe	0.007	0.014
	(0.25)	(0.44)
CONS	1.675***	1.207***
	(5.17)	(3.37)
Year fixed effect	Yes	Yes
Industry fixed effect	Yes	Yes
Adj R2	0.380	0.372
N	18,112	14,990

This table reports endogeneity test results using lagged effect. Column (1) reports the regression results showing the relation between technology independent directors lagged by one year and R&D investment. Column (2) reports the regression results showing the relation between technology independent directors lagged by two years and R&D investment. Two-tailed t-statistics are reported in parentheses. *, **, ***, represent statistical significance at 0.1, 0.05, and 0.01 levels, respectively. Appendix A provides detailed variable definitions.

and repeats the regression of model (2) 1000 times. Coefficients and T-values of the interaction term of the regression results, are shown in Table 9 and Fig. 3. As can be seen from Table 9, the percentage of the 1000 regression results with significant coefficients is relatively small. And the T-values in Fig. 3 are concentrated around 0, implying that the virtual treatment effect does not exist. Therefore, the previous conclusion is robust, and D&O insurance does motivate technology independent directors to serve their fiduciary duties diligently and promote corporate R&D investment.

4.3. Robustness tests

4.3.1. Alternative measures of R&D investment

We use patents as an indicator of technological achievement to fully explain the positive role of technology independent directors in firm strategic decision making. Specifically, the logarithm of 1 plus the number of patents applied (*Patents*) is used to measure patents. Since the number of patents is non-negative, we use tobit model here. From columns (1) and (2) of Table 10, it can be seen that the regression coefficients on *Tech* and *Tech*Ins* are still significantly positive.

4.3.2. Control characteristics of independent directors

To avoid individual characteristics effects of independent directors

Table 6
Endogeneity test 3.

Panel A: Results for propensity score matching approach		
	RD_ratio	
	(1)	(2)
Tech	−0.018	−0.028
	(−0.26)	(−0.40)
Tech*Ins	0.323***	0.331***
	(2.86)	(3.03)
Ins	−0.068	−0.037
	(−1.08)	(−0.62)
Lnasset		−0.020
		(−0.82)
Lev		−0.365**
		(−2.05)
Growth		−0.023
		(−0.52)
ROA		2.587***
		(4.00)
Subsidy		29.987***
		(4.26)
Age		−0.416***
		(−3.93)
Top1		−0.005**
		(−2.26)
Sba		−0.203***
		(−4.18)
Bsize		0.227
		(1.37)
Ind		0.063
		(0.14)
Mgt		1.153**
		(2.46)
Power		0.216**
		(2.31)
Soe		−0.337***
		(−4.04)
CONS	−0.412	1.411**
	(−0.72)	(1.98)
Year fixed effect	Yes	Yes
Industry fixed effect	Yes	Yes
Adj R2	0.342	0.394
N	2756	2756

Panel B: Descriptive statistics for matching variables			
Variables	Treatment mean	Control mean	t-test
Lnasset	23.253	23.253	−0.01 ($p = 0.994$)
Lev	0.527	0.524	0.43 ($p = 0.668$)
Growth	0.174	0.197	−1.23 ($p = 0.218$)
ROA	0.036	0.037	−0.52 ($p = 0.604$)
Age	2.973	2.977	−0.38 ($p = 0.703$)
Sba	0.833	0.859	−0.90 ($p = 0.366$)
Ind	0.376	0.376	0.05 ($p = 0.962$)
Mgt	0.022	0.030	−2.46 ($p = 0.014$)
Power	0.124	0.144	−1.51($p = 0.131$)
Soe	0.698	0.669	1.64 ($p = 0.101$)

This table presents the results for the interactive effect of D&O insurance and technology independent directors on the ratio of R&D investment using matched sample based on propensity score, including control variables assets, leverage, growth rate of sales, return on assets, firm age, shareholding balance, proportion of independent directors, shareholding ratio of managers, chair-CEO duality and state ownership. Panel A presents the regression results based on matched sample. Panel B show the T-test mean difference between treatment and control group. Two-tailed t-statistics are reported in parentheses. *, **, ***, represent statistical significance at 0.1, 0.05, and0.01 levels, respectively. Appendix A provides detailed variable definitions.

on the regression results, we further control variables for age (*Indage*), gender (*Indgender*), number of board seats (*Indsum*) of independent directors, and whether the location of the independent director is consistent with the location of the firm (*Local*). The Columns (3) and (4) of Table 10 show the regression results of model (1) and model (2)

Table 7
Endogeneity test 4: Treatment effect model.

	First stage	Second stage
	Ins	RD_ratio
	(1)	(2)
Ins_province	9.624***	
	(23.18)	
Tech		0.095***
		(4.18)
Tech*Ins		0.219**
		(2.40)
Ins		0.572***
		(3.67)
Lnasset	0.220***	−0.095***
	(14.19)	(−7.78)
Lev	0.220**	−0.148**
	(2.03)	(−2.12)
Growth	−0.018	−0.033
	(−0.49)	(−1.41)
ROA	−0.740**	4.127***
	(−2.16)	(19.28)
Subsidy	1.286	42.385***
	(0.43)	(23.29)
Age	0.512***	−0.500***
	(8.10)	(−13.34)
Top1	−0.002	−0.002**
	(−1.29)	(−2.01)
Sba	0.079**	0.005
	(2.47)	(0.26)
Bsize	0.009	−0.065
	(0.10)	(−0.96)
Ind	0.878***	−0.035
	(2.59)	(−0.15)
Mgt	−1.672***	0.644***
	(−8.55)	(9.09)
Power	−0.138***	0.096***
	(−2.99)	(3.76)
soe	0.197***	−0.007
	(5.00)	(−0.24)
IMR		−0.337***
		(−4.27)
CONS	−8.898***	2.619***
	(−20.45)	(8.04)
Year fixed effect	Yes	Yes
Industry fixed effect	Yes	Yes
Pseudo R2/Wald	0.207	14,542.34
N	21,594	21,594

This table presents the results for the interactive effect of D&O insurance and technology independent directors on the ratio of R&D investment based on treatment effect model. IMR is the Inverse Mills ratio from the first-stage probit regression, where the dependent variable is *Ins*, the independent variables is the ratio of D&O insurance coverage in the province where the firm is located. Two-tailed t-statistics are reported in parentheses. *, **, ***, represent statistical significance at 0.1, 0.05, and 0.01 levels, respectively. Appendix A provides detailed variable definitions.

respectively, the coefficients on *Tech* and *Tech*Ins* do not differ significantly from the previous results.

4.3.3. Replace the sample

Firstly, manufacturing firms occupy a major position in the sample.[3] They are the cornerstone of China's industrial development, and play a key role in high-quality economic development. They also have a strong practical demand for technological innovation. Therefore, we separately select the manufacturing firms for the test, and the regression results of Columns (5) and (6) in Table 10 are basically consistent with the previous ones, indicating that the main conclusions of our study are robust. Secondly, in order to avoid the influence of the inherent characteristics of high-tech firms on previous result, we delete the sample of high-tech
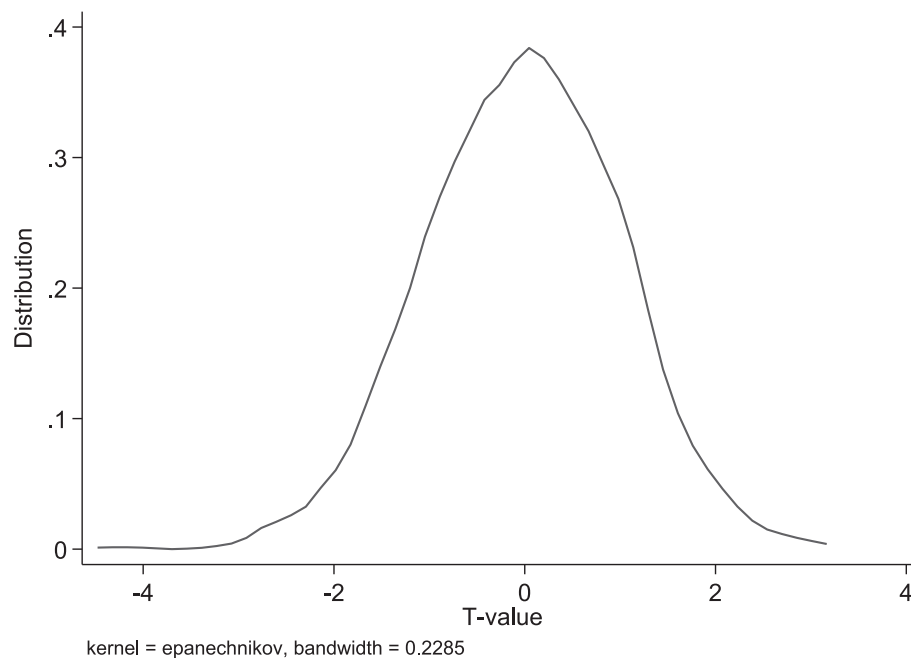
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[3] The industry distribution of our study is shown in Appendix B.

Table 8

Endogeneity test 5: Placebo tests of technology independent directors.

	Mean	P5	P25	P50	P75	P90	P95	SD	N
Coefficient	−0.001	−0.135	−0.056	0.000	0.058	0.099	0.130	0.080	1000
T-values	−0.020	−1.715	−0.708	0.001	0.717	1.248	1.609	1.011	1000

This table presents the results of placebo tests, which randomly assign whether firms with technology independent directors and repeats the regression of model (2) 1000 times. Coefficient is the coefficient of the interaction term *Tech*Ins*.

kernel = epanechnikov, bandwidth = 0.2285

Fig. 2. Kernel density estimate.
This figure presents the the distribution of T-values for the placebo test, which randomly assign whether firms with technology independent directors and repeats the regression of model (2) 1000 times.

Table 9

Endogeneity test 6: Placebo tests of D&O insurance.

	Mean	P5	P25	P50	P75	P90	P95	SD	N
Coefficient	0.005	−0.141	−0.052	0.003	0.069	0.116	0.147	0.090	1000
T-values	0.054	−1.609	−0.596	0.035	0.786	1.287	1.632	1.011	1000

This table presents the results of placebo tests, which randomly assign whether firms purchase D&O insurance and repeats the regression of model (2) 1000 times. Coefficient is the coefficient of the interaction term *Tech*Ins*.

firms and retest model (1) and model (2) again. The regression results do not change significantly, as shown in Columns (7) and (8) of Table 10.

5. Heterogeneity analysis

5.1. The influence of the state ownership

Considering that the state ownership plays a vital role in Chinese firms, it is likely to further influence the incentive effect of D&O insurance. The influence of the state ownership on D&O insurance may come from the following two aspects. First, state-owned and private firms significantly differ in their motivation to purchase D&O insurance. With the increased national support to the insurance industry, D&O insurance has become one of the focal points to promote the innovation of insurance products. Therefore, state-owned firms (SOEs) are more likely to purchase D&O insurance in response to national calls or for personal promotion purposes. In addition, most of the insurance firms in China are SOEs, and state-owned firms naturally become loyal customers of insurance firms. On the contrary, private firms are more

rational in purchasing D&O insurance and have a stronger desire to improve corporate governance and create an excellent corporate governance environment by purchasing D&O insurance. Data in Panel B of Table 1 also show that the coverage ratio of D&O insurance in SOEs is significantly higher than that in private firms. Second, the litigation risk of independent directors in private firms is higher compared with SOEs. Private firms accounted for 67% of 770 incidents of independent directors being penalized from 2002 to 2020. The purchase of D&O insurance is more conducive to alleviating the litigation risk of independent directors of private firms and motivating them to serve their fiduciary duties, thus serving as an incentive. Therefore, we further test the triple interaction of D&O insurance, technology independent directors, and the state ownership.

As can be seen from column (1) of Table 11, the coefficient on the triple interaction term *Tech*Ins*Soe* is significantly negative at the 1% level. In comparison, the coefficient on *Tech*Ins* is still significantly positive at the 1% level, indicating that the purchase of D&O insurance by private firms is more conducive to increasing the promotion effect of R&D investment by technology independent directors compared to
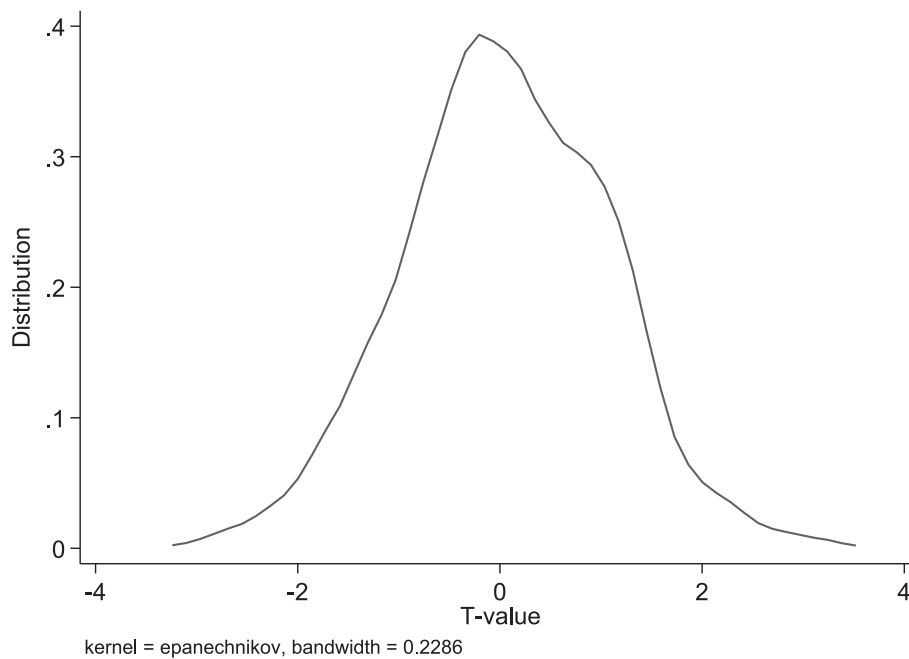
kernel = epanechnikov, bandwidth = 0.2286

Fig. 3. Kernel density estimate.
This figure presents the the distribution of T-values for the placebo test, which randomly assign whether firms with D&O insurance coverage and repeats the regression of model (2) 1000 times.

SOEs. Meanwhile, the coefficient on *Tech*Soe* is not significant, indicating that the moderating effect of the state ownership in the triple interaction term is realized through the D&O insurance rather than through the technology independent directors. In addition, it is found in columns (2) and (3) of Table 11 by group test that the coefficient on *Tech*Ins* is significantly positive at the 1% level in the sample of private firms. In contrast, the coefficient on *Tech*Ins* is not significant in the sample of SOEs. And the coefficients between the two groups differ at the 1% level, again verifying the existence of the moderating effect of the state ownership.

To better understand the moderating effect of state ownership, we further compare the marginal effects of *Tech* on *RD_ratio* under different state ownership and whether they purchased D&O insurance, as shown in Table 12 and Fig. 4. In Table 12, the marginal effect of technology independent directors in private firms with D&O insurance coverage (b = 0.962, *t* = 3.52) is significantly stronger than that in private firms without D&O insurance coverage (b = 0.083, *t* = 2.75). However, the marginal effect of technology independent directors in SOEs with D&O insurance coverage is weak (*t* = 1.87). As shown in Fig. 4, for private firms without D&O insurance coverage, R&D investment increased by 4.11% when technology independent directors changed from zero to one; for private firms with D&O insurance coverage, R&D investment increases by 43.24% when technology independent directors changed from zero to one. However, the moderating effect of D&O insurance and technology independent directors in SOEs is insignificant. Therefore, compared with SOEs, purchasing D&O insurance by private firms is more conducive to improving the promotion effect of technology independent directors on firm R&D investment.

5.2. The influence of the characteristics of technology independent directors

D&O insurance can transfer the litigation risk of independent directors and affect the trade-off between risk and benefit of independent directors, which ultimately acts on their behavior. However, independent directors have varying perceptions of litigation risk and risk tolerance due to their individual motivations and characteristics. The choice made by multiple independent directors of the same firm, even when faced with the same risk, is not the same. For example, faced with the same risk, some independent directors of the firm will choose to resign, while some will keep their positions. Both Dewally and Peck (2010) and Jiang, Wan, and Zhao (2016) find that younger independent directors have stronger risk perceptions and weaker tolerance. It can be seen that the characteristics of independent directors also affect their risk tolerance, which in turn influence the incentive effect of D&O insurance. Therefore, we use *Age_tech* to represent the demographic characteristics of technology independent directors and further tests the interaction between D&O insurance and the characteristics of technology independent directors.

Column (4) of Table 11 reported the moderating effect of the age of technology independent directors. The regression results show that the coefficient on *Age_tech*Ins* is significantly negative, indicating that the younger the technology independent director is, the more favorable the incentive effect of D&O insurance is and the stronger the promotion effect of R&D investment by technology independent directors is. The reason may be that younger technology independent directors have longer careers, value their futures and reputations more, and have a lower tolerance for risks than older technology independent directors.

Table 10
Robustness tests.

	Patents		RD_ratio					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Tech	0.051***	0.042**	0.112***	0.103***	0.117 ***	0.099 ***	0.130***	0.120***
	(2.56)	(2.10)	(5.08)	(4.49)	(4.14)	(3.43)	(5.06)	(4.48)
Tech*Ins		0.178*		0.181**		0.461 ***		0.173*
		(1.85)		(2.02)		(2.91)		(1.95)
Ins		0.026		−0.047		−0.165**		0.024
		(0.54)		(−1.00)		(−2.14)		(0.51)
Lnasset	0.132***	0.129***	−0.087***	−0.087***	−0.082 ***	−0.082 ***	−0.079***	−0.082***
	(12.68)	(12.31)	(−7.40)	(−7.44)	(−5.20)	(−5.27)	(−6.59)	(−6.71)
Lev	−0.039	−0.038	−0.181***	−0.180***	−0.089	−0.090	−0.145*	−0.144*
	(−0.69)	(−0.69)	(−2.57)	(−2.57)	(−1.01)	(−1.02)	(−1.89)	(−1.88)
Growth	−0.023	−0.022	−0.045**	−0.044**	−0.071 **	−0.069 **	−0.029	−0.028
	(−1.31)	(−1.24)	(−2.19)	(−2.15)	(−2.38)	(−2.32)	(−1.40)	(−1.35)
ROA	0.809***	0.820***	4.136***	4.140***	4.327 ***	4.325 ***	2.866***	2.881***
	(4.52)	(4.59)	(15.89)	(15.90)	(14.21)	(14.22)	(9.70)	(9.75)
Subsidy	6.337***	6.297***	35.553***	35.536***	47.708 ***	47.644 ***	22.761***	22.715***
	(3.81)	(3.79)	(13.10)	(13.09)	(14.56)	(14.54)	(7.76)	(7.75)
Age	−0.267***	−0.271***	−0.447***	−0.447***	−0.527***	−0.524***	−0.363***	−0.366***
	(−7.75)	(−7.85)	(−11.44)	(−11.46)	(−11.29)	(−11.24)	(−7.60)	(−7.67)
Top1	−0.002**	−0.002**	−0.002**	−0.002**	−0.001	−0.001	0.002	0.002
	(−2.44)	(−2.47)	(−2.15)	(−2.17)	(−0.69)	(−0.74)	(1.49)	(1.50)
Sba	−0.036**	−0.038**	0.004	0.003	−0.014	−0.015	0.068***	0.067***
	(−2.08)	(−2.17)	(0.19)	(0.16)	(−0.51)	(−0.56)	(2.76)	(2.72)
Bsize	−0.151***	−0.153***	−0.036	−0.038	−0.061	−0.059	−0.196**	−0.199***
	(−2.57)	(−2.61)	(−0.51)	(−0.53)	(−0.65)	(−0.63)	(−2.54)	(−2.58)
Ind	−0.579***	−0.591***	−0.010	−0.012	−0.112	−0.102	−0.501**	−0.516**
	(−2.76)	(−2.82)	(−0.04)	(−0.05)	(−0.38)	(−0.34)	(−2.00)	(−2.06)
Mgt	−0.023	−0.019	0.623***	0.625***	0.565 ***	0.567 ***	0.995***	0.998***
	(−0.38)	(−0.32)	(8.07)	(8.10)	(6.66)	(6.69)	(9.84)	(9.88)
Power	0.003	0.004	0.092***	0.092***	0.143***	0.142***	0.082**	0.082**
	(0.15)	(0.16)	(3.35)	(3.35)	(4.50)	(4.47)	(2.55)	(2.56)
Soe	0.143***	0.140***	0.026	0.024	0.086**	0.083**	−0.012	−0.015
	(6.15)	(6.01)	(0.91)	(0.85)	(2.35)	(2.24)	(−0.41)	(−0.51)
Indage			0.114	0.115				
			(1.02)	(1.03)				
Indgender			−0.140**	−0.139**				
			(−2.52)	(−2.50)				
Indsum			0.087***	0.086***				
			(6.66)	(6.61)				
Local			0.071***	0.070***				
			(3.23)	(3.20)				
CONS	−1.533***	−1.450***	1.868***	1.891***	3.351***	3.363***	2.617***	2.703***
	(−5.65)	(−5.31)	(3.90)	(4.52)	(8.35)	(8.50)	(8.14)	(8.33)
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effect	Yes	Yes	Yes	Yes	No	No	Yes	Yes
Pseudo R2/Adj R2	0.019	0.019	0.382	0.382	0.209	0.210	0.374	0.374
N	21,594	21,594	19,689	19,689	13,867	13,867	12,169	12,169

This table presents the robustness tests results on the relationship between technology independent directors and R&D investment (column (1)(3)(5)(7)) and the effect of D&O insurance on them (column (2)(4)(6)(8)). Columns (1) and (2) are the regression results with *Patents* as the dependent variable. Columns (3) and (4) are the regression results with control variables of individual characteristics of independent directors. Columns (5) and (6) are the regression results used the sample of manufacturing firms. Columns (7) and (8) are the regression results used the sample of non-high-tech firms. Two-tailed t-statistics are reported in parentheses. *, **, ***, represent statistical significance at 0.1, 0.05, and 0.01 levels, respectively. Appendix A provides detailed variable definitions.

Table 11
The heterogeneity analysis.

	RD_ratio			
	(1)	(2)	(3)	(4)
Tech	0.071**	0.108***	0.083***	
	(2.44)	(3.11)	(2.75)	
Tech*Ins	0.886***	0.010	0.879***	
	(3.20)	(0.14)	(3.19)	
Tech*Ins*Soe	−0.862***			
	(−3.02)			
Tech*Soe	0.060			
	(1.37)			
Ins*Soe	−0.339***			
	(−3.03)			
Age_tech				0.007***
				(4.01)
Age_tech*Ins				−0.016*
				(−1.80)
Ins	0.179*	−0.151***	0.209**	1.075**
	(1.76)	(−3.37)	(2.05)	(2.14)
Lnasset	−0.072***	−0.042***	−0.097***	−0.103***
	(−6.50)	(−2.94)	(−5.42)	(−5.82)
Lev	−0.158**	−0.234**	−0.122	−0.262**
	(−2.29)	(−2.46)	(−1.26)	(−2.36)
Growth	−0.036*	0.053*	−0.080***	−0.068*
	(−1.74)	(1.77)	(−2.92)	(−1.84)
ROA	4.028***	3.278***	4.293***	4.268***
	(16.05)	(8.80)	(13.08)	(12.41)
Subsidy	42.547***	27.775***	54.460***	52.701***
	(16.01)	(7.60)	(14.31)	(18.80)
Age	−0.479***	−0.556***	−0.425***	−0.310***
	(−12.71)	(−7.93)	(−9.42)	(−5.75)
Top1	−0.002*	−0.005***	−0.002	−0.003*
	(−1.80)	(−2.94)	(−1.29)	(−1.83)
Sba	0.016	−0.076**	0.024	−0.009
	(0.77)	(−2.30)	(0.93)	(−0.29)
Bsize	−0.065	−0.066	−0.030	−0.084
	(−0.94)	(−0.72)	(−0.29)	(−0.80)
Ind	0.052	−0.301	0.271	0.323
	(0.23)	(−1.01)	(0.79)	(0.91)
Mgt	0.660***	4.302***	0.544***	0.440***
	(8.76)	(6.40)	(6.85)	(4.30)
Power	0.094***	−0.060	0.134***	0.075*
	(3.58)	(−1.17)	(4.37)	(1.95)
Soe	0.022			0.011
	(0.69)			(0.27)
CONS	2.058***	2.057***	2.222***	2.349***
	(7.07)	(5.63)	(4.49)	(5.02)
Year fixed effect	Yes	Yes	Yes	Yes
Industry fixed effect	Yes	Yes	Yes	Yes
Adj R2	0.388	0.350	0.355	0.359
N	21,594	8866	12,728	8997
The coefficient test between groups	P-value = 0.002			

This table presents the moderating effect of state ownership (column (1)–(3)) and age of technology independent directors (column (4)). Column (1) use the full sample. Column (2) use the state-owned firms sample. Column (3) use the private firms sample. Column (4) use the samples with technology independent directors. Two-tailed t-statistics are reported in parentheses. *, **, ***, represent statistical significance at 0.1, 0.05, and 0.01 levels, respectively. Appendix A provides detailed variable definitions.

Table 12
Marginal effects of technology independent directors on firm R&D investment under different state ownership.

state ownership	D&O insurance	Marginal Effect	T-values
State-owned firms (SOEs)	Not purchased	0.108	3.11
State-owned firms (SOEs)	Already purchased	0.118	1.87
Private firms	Not purchased	0.083	2.75
Private firms	Already purchased	0.962	3.52

However, D&O insurance transfers the risks of independent directors, significantly improves their risk tolerance, stimulates their enthusiasm in serving their fiduciary duties, and exerts a more significant incentive effect.

6. Additional analysis

We further discuss the internal mechanism of the moderating role of D&O insurance and hold that its path is to reduce the risks of independent directors, stimulate their enthusiasm to serve their fiduciary duties, and then improve the level of corporate R&D investment, form effective performance. The direct target of D&O insurance should be the actions of directors and officers. However, the main ways of independent directors to serve their fiduciary duties are participation in board meetings and the issuance of independent opinions. The issuance of independent opinions are more representative of the diligence than participation in board meetings. This view has been confirmed by previous studies (Dewally & Peck, 2010). Therefore, we argue that if the purchase of D&O insurance indeed increases the risk tolerance of technology independent directors, it will enhance their independence, prompt them to issue independent opinions more boldly or even dissenting opinions, and eventually form a more diligent performance.

In our study, the influence of D&O insurance on independent directors' diligence performance is tested by using Now (the number of words in opinion reports), Ndili (the number of diligence words in opinion reports) and Neg (whether to "say no") as the measurement standards. The scope of diligence words is adapted from the "diligence dictionary" in Jia and Tang (2018), and partially adjusted and added as shown in Table 13. Table 14 reports the corresponding regression results. Based on the results from columns (1) to (3), we can observe that the coefficients on Ins are all positive and significant at the 1% level, indicating that D&O insurance does improve the diligence of independent directors' performance. It is demonstrated by the higher number of words in the opinion reports, the higher number of diligence words, and the higher likelihood of dissenting opinions. To sum up, the intrinsic mechanism of the moderating effect of D&O insurance on technology independent directors and firm R&D investment can be expressed as the enhancement of diligent performance behavior formed by the reduction of risks, i.e., the incentive effect of D&O insurance.

To further ensure the robustness of additional analysis result, we use two-stage instrumental variable approach and PSM approach for testing. First, we use the ratio of D&O insurance coverage in the province where the firm is located (Ins_province) as an instrumental variable. As mentioned above, Ins_province will directly affect the firm's willingness to purchase D&O insurance. However, there is no evidence that Ins_province will directly affect the behavior of independent directors. Therefore, we believe that our instrumental variable satisfies both relevance and exclusivity. The first-stage regression results are shown in column (1) of Appendix C. The minimum eigenvalue statistic is 582.313, supporting the validity of our instruments. The second-stage regression results are shown in column (2)–(4) of Appendix C. The results are consistent with above conclusion, the incentive effect of D&O insurance is verified again. Second, to avoid sample selection bias and potentially misleading conclusions, we use PSM approach. A sample of firms with D&O insurance coverage is matched with a control group of firms that are very close in firm characteristics but without D&O insurance coverage. The matching results are shown in Panel B of Table 6. We use the matched samples to re-regress the behavior of independent directors on D&O insurance, as shown in Appendix D. The results have not changed significantly, indicating that the above conclusion is robust.
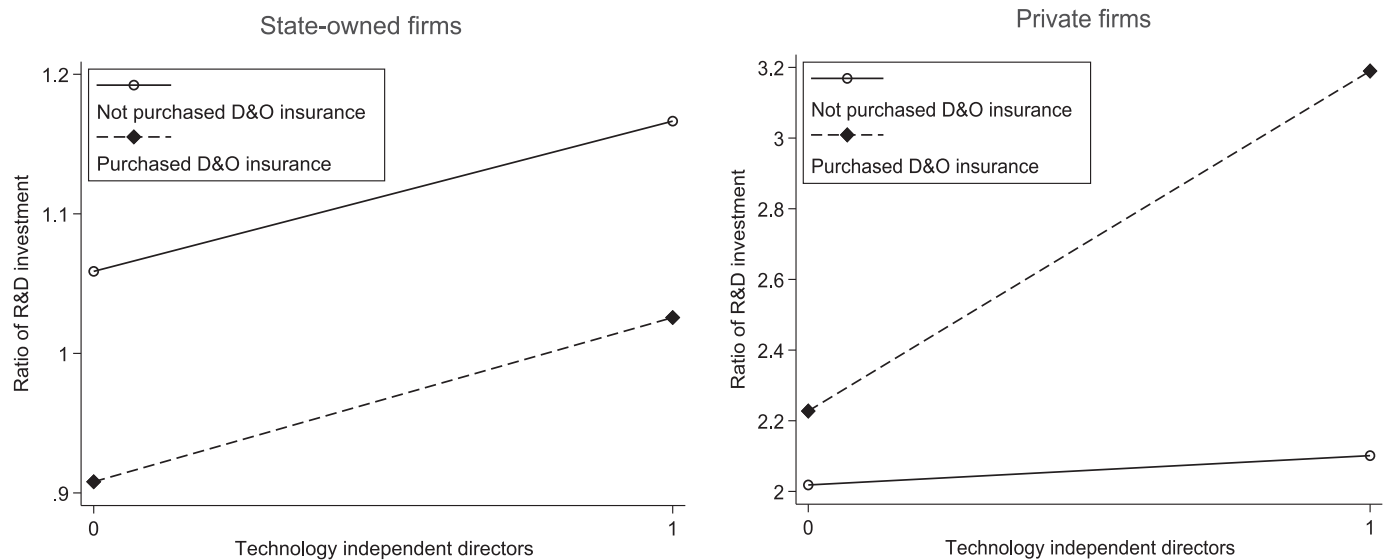
Fig. 4. Moderating effects of state ownership.
This figure presents the moderating effects of state ownership.

Table 13
Scope of diligence words in independent directors' opinions.

Check, Verify, Non-conformity, Error, Suspicion, As soon as possible, Caution, Strengthen, Understand, Inventory, Incomplete, Missing, Hidden, Eradicate, Must, Adjust, Audit, Investigation, Inadequate, Failure, Defects, Prudent, Efforts, Improvement, Inquiries, Questioning, Untimely, Criticism, Failure, Effective, Serious, Enhancement, Review, Consideration, Insufficient detail, Flawed, Strictly, Active, Thoroughly, Strengthened, Examine, Supervision, Inaction

7. Conclusions and suggestions

By using the data of Chinese A-share listed firms from 2008 to 2020 as a sample, this paper takes the effect of technology independent directors' performance as a research object and examines the impact and mechanism of D&O insurance on technology independent directors' performance. The study finds that D&O insurance promote the diligence of technology independent directors and produce an incentive effect, thus increasing their contribution to firm R&D investment and improving the effectiveness of technology independent directors in serving their fiduciary duties. These results remain robust after controlling for potential endogeneity problems. The heterogeneity analysis finds that state ownership plays a moderating role in the incentive effect of D&O insurance. Specifically, the incentive effect of D&O insurance is more significant in private firms, and technology independent directors have a more pronounced promotion effect on corporate R&D investment. However, the same results are not found in state-owned firms. Meanwhile, the characteristics of technology independent directors also influence the incentive effect of D&O insurance, which is stronger in the younger group. In the additional analysis, it is found that the incentive effect of D&O insurance can be manifested as independent directors are more willing to issue diligent opinions and bolder to issue dissenting opinions, which eventually results in effective behavior. The findings of this paper suggest that D&O insurance are beneficial in motivating independent directors to serve their fiduciary duties, providing new empirical evidence on the governance effects of D&O insurance in emerging markets and among independent director groups.

Table 14
Additional analysis results.

	Now (1)	Ndili (2)	Neg (4)
Ins	0.051*** (5.64)	0.210*** (5.05)	0.257*** (2.57)
Lnasset	0.006*** (2.78)	−0.029*** (−3.00)	−0.044 (−1.44)
Lev	0.104*** (8.11)	0.465*** (7.65)	0.111 (0.57)
Growth	0.030*** (7.13)	0.110*** (5.51)	−0.067 (−0.95)
ROA	0.004 (0.11)	0.039 (0.21)	−1.616*** (−2.71)
Age	−0.026*** (−4.35)	0.037 (1.21)	0.228** (2.08)
Top1	0.000** (2.49)	0.003*** (3.50)	−0.003 (−1.06)
Sba	0.019*** (5.65)	0.029* (1.71)	0.076 (1.58)
Bsize	−0.017 (−1.41)	−0.031 (−0.55)	0.137 (0.76)
Ind	0.070* (1.70)	0.152 (0.76)	0.410 (0.64)
Power	0.006 (1.50)	0.014 (0.66)	0.027 (0.40)
Soe	−0.033*** (−7.10)	−0.087*** (−3.92)	−0.010 (−0.15)
CONS	5.998*** (98.83)	2.475*** (9.29)	−2.254*** (−2.71)
Year fixed effect	Yes	Yes	Yes
Industry fixed effect	Yes	Yes	Yes
Adj R2/Pseudo R2	0.048	0.053	0.061
N	18,543	18,543	18,543

This table presents the impact of D&O insurance coverage on independent directors' diligence performance. Columns (1)–(3) are the regression results with *Now*, *Ndili* and *Neg* as the dependent variable, respectively. Two-tailed t-statistics are reported in parentheses. *, **, ***, represent statistical significance at 0.1, 0.05, and 0.01 levels, respectively. Appendix A provides detailed variable definitions.

Based on the above findings, we put forward the following policy recommendations. First, independent directors, as a special group of directors, have an asymmetry of risk-benefit, and D&O insurance positively affects their behavior by transferring risks. It is suggested that the regulators should incorporate D&O insurance into the institutional framework of independent directors and actively encourage listed firms to purchase performance insurance for independent directors to reduce their risks and enhance the effectiveness of their performances. Second, although there are two opposing views of D&O insurance in corporate governance, i.e., the incentive view and the self-interest view, the impact of D&O insurance on directors and officers will differ depending on their positions and characteristics. The government and regulators should pay more attention to the positive governance role of D&O insurance, continuously improve internal and external governance mechanisms, and thus enhance corporate governance. Finally, considering that the incentive effect of D&O insurance in private firms is obviously better than that of state-owned firms, China should continue to promote the Mixed-ownership Reform of state-owned firms, improve the corporate governance structure, and enhance the vitality of the state-owned economy.

Appendix A. Variable definitions

Variables	Definition
Dependent variables	
RD_ratio	The ratio of R&D investment to total assets multiply by 100.
Independent variables	
Tech	A dummy variable that equals 1 if firm i with technology background independent directors in year t, and 0 otherwise.
Moderators	
Ins	A dummy variable that equals 1 if the firm i has purchased D&O insurance in year t, and 0 otherwise.
Soe	A dummy variable that equals 1 if the firm i is a state-owned enterprise in year t, and 0 otherwise.
Age_tech	The average age of technology independent directors in firm i.
Control variables	
Lnasset	The natural logarithm of the total assets.
Lev	The ratio of total liabilities to total assets.
Age	The natural logarithm of the firm age.
Subsidy	The total number of detailed items of government subsidies.
Top1	The shareholding percentage of the largest shareholder.
Sba	The ratio of the shareholding of the second to tenth largest shareholders to the shareholding of the first largest shareholder.
Bsize	The natural logarithm of the number of board members.
Ind	The ratio of the number of independent directors to the total number of directors.
Mgt	The ratio of shares held by managers to the total shares.
Growth	The growth rate of firm sales.
ROA	The ratio of net income to total assets.
Power	A dummy variable that equals 1 if the chairman and CEO are the same person, and 0 otherwise.
Indage	The average age of total independent directors.
Indgender	A dummy variable that equals 1if female independent directors on the board, and 0 otherwise.
Indsum	The average board seats of total independent directors.
Local	A dummy variable that equals 1 if the location of any independent director is consistent with the location of the firm in year t, and 0 otherwise.
Patents	The natural logarithm of 1 plus the number of patent applied.
University	The natural logarithm of the number of science, technology, agriculture and medicine universities in the province where the firm is located.
Ins_province	The ratio of firms with D&O insurance coverage in province where the firm is located.
Tech_1	A dummy variable that equals 1 if firm i with technology background independent directors in year t-1, and 0 otherwise.
Tech_2	A dummy variable that equals 1 if firm i with technology background independent directors in year t-2, and 0 otherwise.
Now	The natural logarithm of the average number of words in independent directors' opinions reports.
Ndili	The average number of diligence words in independent directors' opinions reports.
Neg	A dummy variable that equals 1 if any independent director casts a vote that is not a "FOR"vote, and 0 otherwise.

Appendix B. Industry distribution

Industry	Frequency	Percentage	Cumulative Percentage
Agriculture, forestry, animal husbandry and fishery industry	309	1.43	1.43
Mining industry	515	2.38	3.82
Manufacturing industry	13,867	64.22	68.03
Electricity, heat and gas industry	750	3.47	71.51
Construction industry	54	2.52	74.03
Wholesale and retail industry	1175	5.44	79.47
Transportation, storage and postal services industry	727	3.37	82.84
Hotel and catering industry	96	0.44	83.28
Information transmission, software and information technology services industry	1301	6.02	89.31
Real estate industry	1078	4.99	94.30
Leasing and business services industry	264	1.22	95.52
Scientific research and technical services industry	178	0.82	96.35

(*continued*)

Industry	Frequency	Percentage	Cumulative Percentage
Water conservancy, environment and public facilities management industry	257	1.19	97.54
Residential services and repair industry	15	0.07	97.61
Education industry	16	0.07	97.68
Health and social work industry	46	0.21	97.89
Culture, sports and entertainment industry	224	1.04	98.93
Synthesis	231	1.07	100.00
Total	21,594	100.00	

Appendix C. Instrumental variable results in additional analysis

	First stage	Second stage		
	Ins	*Now*	*Ndili*	*Neg*
	(1)	(2)	(3)	(4)
Ins_province	1.043***			
	(20.79)			
Ins(IV)		0.229***	0.444*	0.035*
		(4.49)	(1.90)	(1.95)
Lnasset	0.031***	0.000	−0.036***	−0.002**
	(13.72)	(0.14)	(−2.92)	(−2.03)
Lev	0.007	0.105***	0.465***	0.003
	(0.66)	(8.10)	(7.66)	(0.47)
Growth	−0.005	0.031***	0.111***	−0.002
	(−1.39)	(7.32)	(5.60)	(−1.08)
ROA	−0.108***	0.024	0.063	−0.049**
	(−3.16)	(0.64)	(0.33)	(−2.49)
Age	0.054***	−0.035***	0.025	0.004
	(10.34)	(−5.45)	(0.76)	(1.33)
Top1	−0.000	0.001**	0.003***	−0.000
	(−0.58)	(2.54)	(3.52)	(−0.73)
Sba	0.006**	0.018***	0.027	0.002
	(2.12)	(5.17)	(1.61)	(1.46)
Bsize	0.009	−0.019	−0.033	0.003
	(0.89)	(−1.48)	(−0.58)	(0.67)
Ind	0.116***	0.046	0.120	0.010
	(3.23)	(1.09)	(0.59)	(0.55)
Power	−0.009***	0.007*	0.015	0.001
	(−2.68)	(1.75)	(0.72)	(0.37)
Soe	0.027***	−0.038***	−0.092***	−0.001
	(6.31)	(−7.70)	(−4.01)	(−0.78)
CONS	−0.905***	6.147***	2.661***	0.038
	(−15.05)	(83.05)	(8.01)	(1.48)
Year fixed effect	Yes	Yes	Yes	Yes
Industry fixed effect	Yes	Yes	Yes	Yes
Adj R2/Pseudo R2	0.094	0.048	0.051	0.004
N	18,543	18,543	18,543	18,543
Minimum eigenvalue statistic	582.313			

This table reports endogeneity test results using two-stage IV approach. Column (1) reports the first stage regression results showing the relation between *Ins_province* and *Ins*, and the fitted value is used in place of *Ins* in column (2)–(4). Column (4) repeat the additional analysis by replacing *Ins* with its fitted values computed in the first stage. Two-tailed t-statistics are reported in parentheses. *, **, ***, represent statistical significance at 0.1, 0.05, and 0.01 levels, respectively. Appendix A provides detailed variable definitions.

Appendix D. PSM results in additional analysis

	Now	*Ndili*	*Neg*
	(1)	(2)	(4)
Ins	0.056***	0.200***	0.005
	(4.78)	(3.72)	(0.87)
Lnasset	0.013**	−0.064***	−0.002
	(2.37)	(−2.59)	(−1.01)
Lev	0.013	0.519***	0.010
	(0.29)	(2.63)	(0.50)
Growth	0.034***	0.246***	−0.000
	(2.77)	(4.26)	(−0.05)
ROA	−0.011	−0.601	−0.030
	(−0.09)	(−0.99)	(−0.42)
Age	0.030	0.309***	0.004
	(1.22)	(2.63)	(0.42)

(*continued on next page*)

(*continued*)

	Now	Ndili	Neg
	(1)	(2)	(4)
Top1	−0.000	−0.001	0.000
	(−0.15)	(−0.30)	(0.40)
Sba	0.001	−0.079	0.007
	(0.10)	(−1.43)	(0.96)
Bsize	0.037	0.299**	0.005
	(1.03)	(1.97)	(0.40)
Ind	−0.013	0.378	−0.050
	(−0.11)	(0.66)	(−0.88)
Power	−0.019	−0.091	−0.005
	(−1.15)	(−1.10)	(−0.54)
Soe	−0.074***	−0.354***	−0.008
	(−5.37)	(−5.10)	(−1.17)
CONS	5.786***	2.132***	0.045
	(35.29)	(2.90)	(0.67)
Year fixed effect	Yes	Yes	Yes
Industry fixed effect	Yes	Yes	Yes
Adj R2/Pseudo R2	0.051	0.088	0.018
N	2328	2328	2328

This table presents the impact of D&O insurance coverage on independent directors' diligence performance using matched sample based on propensity score. Columns (1)–(3) are the regression results with *Now*, *Ndili* and *Neg* as the dependent variable, respectively. Two-tailed t-statistics are reported in parentheses. *, **, ***, represent statistical significance at 0.1, 0.05, and 0.01 levels, respectively. Appendix A provides detailed variable definitions.

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