Specialist vs. Generalist: Which Type of Independent Director is Better at Increasing Innovation?

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ABSTRACT

Using data from listed firms in China from 2007 to 2017, this study examines the effect of adding technical independent directors to boards of directors, specifically whether firms' innovation performance is influenced by the relevance of the directors' expertise to the corporate business. The results show that when a technical independent director's specialty is relevant to the corporate operational field, the firm should have better innovation performance. Moreover, technical independent directors exert influence on innovation mainly by promoting firms to dig deeper in their current field of research, instead of expanding to other fields. Our findings can guide corporations to hire more relevant technical independent directors, and aid the government in designing more accurate policies to promote innovation and entrepreneurship.

Keywords: academic and industry collaboration; technical independent directors; corporate innovation performance; innovation patents

1. Introduction

When China was facing an economic slowdown after decades of fast growth, the Premier, Keqiang Li, stated that the key to further development is strengthened cooperation between industries and research institutions. This spurred increased interest in the combination of theoretical study and practical application. Increasingly, independent directors, a natural bridge between universities and enterprises, emerged from universities.

Since 2001, the Securities and Exchange Commission has regulated that at least one-third of the board of publicly-traded firms in China must be independent directors. According to Ferris and Pritchard (2003), independent directors play two roles: supervisors and consultants. As supervisors, they monitor and evaluate the performance of managers and exert their influence on setting managers' compensation. As consultants, they give professional advice on business operations and strengthen firms' research capabilities.

Acting as supervisors, independent directors are less likely to conspire with managers (Fama and Jensen, 1983), as they are placed on the board through a nomination process (Cavaco et al., 2017), and tend to be more sensitive to outside opinions of the corporation (Laux, 2008). Thus, independent directors can effectively monitor corporate operations. Agrawal and Chadha (2005) found that when an audit committee has some independent directors with CPA or CFA qualifications, the firm has better earnings management. That study solely focused on independent directors with financial backgrounds and did not particularly study all technically-trained independent directors. Moreover, if the cost of information is relatively high in a corporation, an increased number of independent directors could have a negative effect on corporate performance (Duchin et al., 2010; Cavaco et al., 2017).

Acting as consultants, independent directors can support a corporation by providing external communication channels and reducing information costs (Bazerman and Schoorman, 1983). They can also provide many valuable suggestions that insiders are unable to offer (Dalton et al., 1999). Fich and White (2005) found that when an outside CEO is designated to a board, the firm's potential could be better achieved, especially when the CEO is from the same industry with relevant business knowledge. That study, however, looked generally at all board members and did not specifically study independent directors.

Some studies state that specific knowledge about the industry is crucial to a corporation (Coles et al., 2008; Linck et al., 2008). Furthermore, Audretsch et al. (2006) found that technological corporations tend to assign scholars as independent directors, aiming to compensate for the lack of professional knowledge. Similarly, White et al. (2014) found that fast growing, large corporations tend to appoint academic independent directors. Ronald and Emma (2018) provided evidence that if independent directors are distracted, the corporation will witness a decline in firm-specific knowledge and a reduced board commitment. While the existing literature has identified the tendency for some types of corporations to hire scholars as independent directors, they have not identified the reason. In this paper, we will supplement past literature by examining whether having more relevant academic independent directors helps a firm as well as the mechanism they use to exert their influence over a corporation.

At present, the literature on the relationship between technical independent directors and corporate innovation performance is still limited. On the one hand, technical independent directors may use their expertise as “specialists” to help enterprises improve their innovation performance. On the other hand, since an enterprise is highly familiar with its main business, the effect of employing a highly matched “specialist” may not be as strong as hiring a poorly matched “generalist.” In addition, since independent directors have no actual control over an enterprise, it is difficult to judge the actual effect of an independent director on an enterprise’s innovation performance. Whether technical independent directors can improve corporate innovation performance needs further empirical analysis and evaluation.

Using panel data of listed firms on the Shanghai Stock Exchange (SSE) and the Shenzhen Stock Exchange (SZSE) in China from 2007 to 2017, this paper will explore whether matching the expertise of independent directors and corporate businesses influence the application and authorization of innovation patents. In China, there are three types of patents: technical invention patents, utility patents, and design patents. Since design and utility patents only indicate changes in the look or functions of existing products, and technical invention patents refer to the invention of a brand-new product, this paper uses technical invention patents as the measurement of real innovation; the other two types of patents are considered strategic innovations.

We used the rate of technical invention patent applications to measure the quantity of innovation and rates of authorization to measure the quality of innovation. Through empirical studies, we found that when independent directors’ expertise is more relevant to the corporate business, the application rate for technical invention patents are expected to see a great increase, and that for design patents are expected to decrease, while that for the utility patents will not see a statistically significant result. Thus, from the quantity side, the corporation is witnessing a better innovation performance, since it allocates more resources to the technical invention patents, which is of higher quality than the other two types. Moreover, similar results were obtained for the authorization rates, which indicate that the corporation is getting better in the quality of innovation performance as well. Based on the findings, we can conclude that technical independent directors can use their expertise and information to help listed companies to perform technological innovation and provide technical guidance. Therefore, if companies hire independent directors whose expertise is more relevant to their business, we will expect better innovation performance of the industries, as well as healthier growth of the economy. Furthermore, we further studied how technical independent directors play their consulting roles within the firm, and we found that they prefer to utilize their own knowledge to help corporations to dig into the current research field instead of expanding to other relevant fields. It is of great practical importance for firms if they want to introduce cutting-edge breakthroughs and gain some competitive advantages within the industry.

Compared with the existing empirical studies, this paper has three main contributions. First, in terms of the educational background of independent directors, most prior literature only identifies the academic major of independent directors; few studies examine their research experience. To begin we will look at theories on the characteristics of independent directors. Through manual data collection and processing, this study explores how the correlation between a director’s experience and the match between experience and the firm’s main business influences the innovation performance of the firm.

Second, we will expand the latest literature on the advisory functions of a board. At present, no literature has specifically pointed out whether the consulting role of independent directors can improve firms' innovation performance. From the perspective of corporate governance for listed companies, we focus on the consulting role of independent directors in terms of corporate innovation and provide more evidence for how an independent director system can play a role in corporate governance and decision-making.

Third, our findings can provide guidance for both corporations and governments in improving innovation capabilities. Although the concept of combining industry operations and academic research has been promoted for decades and the government has enacted relevant policies, corporations may mistakenly focus on strategic innovation, rather than technical innovation. On the other hand, if firms hire more independent directors who are relevant to their business, both the application and authorization rates of design patents may decrease.

The rest of this paper is structured as follows: the second part includes the literature review and research hypothesis; the third part includes the descriptive statistics; the fourth , fifth, and sixth parts report and analyze the results of empirical tests; and the seventh part summarizes the conclusions and policy implications.

2. Literature Review and Hypothesis Development

This paper is based upon two literature streams. The first stream explores the relationship between the characteristics of independent directors as outsiders and enterprises' decisions. The second stream is related to the factors that stimulate innovation within a corporation.

Currently, many studies have reached the conclusion that independent directors, with little or no ties to a company, can significantly influence corporate performance, positively and negatively. For instance, independent directors can limit managerial discretion because they can punish managers after undesirable outcomes (Fama and Jensen, 1983). Ahmed and Duellman (2007) found that firms with a higher proportion of independent directors recognize losses timelier, suggesting they have higher earnings quality. Ferreira et al. (2011) found a positive relationship between the proportion of independent directors and earnings informativeness. Other studies also show a positive correlation between the presence of independent directors and corporate performance (e.g., Rosenstein and Wyatt, 1990; Ferris et al., 2003; Honeine and Swan, 2010; Armstrong et al., 2014; Al-dhamari et al., 2017). In contrast, empirical work by Yermack (1996) showed that having a smaller proportion of independent directors on a board results in better corporate performance; several other studies also reach the same conclusion (e.g., Bhagat and Black, 2002; Anderson et al., 2004; Boone et al., 2007).

Furthermore, many studies have focused on different characteristics of independent directors and how they affect the operation of companies. Adams and Ferreira (2009) found that female directors have a significant impact on board inputs and firm outcomes, using a sample of US firms. Masulis and Mobbs (2014) claimed that firms with independent directors experiencing an exogenous increase in a directorship's relative ranking will see improvements in performance. Other characteristics studied include independent directors' background (Gang et al., 2007), gender (Shukeri et al., 2012; Ferreira et al., 2018), reputation (Brochet and Srinivasan, 2014; Fos et al., 2017), and tenure (Bonini et al., 2017).

Moreover, recent studies have addressed the mechanism for independent directors' characteristics in influencing corporate innovations. In general, independent directors play two roles: monitors and consultants (Ferris and Pritchard, 2003). The role of monitoring can be considered as an intrinsic requirement of the position, and the role as a consultant allows more freedom. As monitors, outside board members increase board oversight of corporate operations (Benjamin et al., 2016) and can terminate managers for poor performance (Weisbach, 1988), which in turn, incentivizes managers to perform well (Sitglitz and Weiss, 1983). Innovation falls into the category of daily operation; thus, innovation could be enhanced by stronger board control. As consultants, independent directors can help companies discover solutions at a lower cost than outside consulting services. Jiraporn et al. (2017) investigated the effect of independent directors on corporate innovation by using R&D investment to quantify innovation performance; they concluded that board governance has a palpable effect on innovation productivity. Other similar studies found significant correlation between independent board members' characteristic and innovation; however these mainly dealt with the proportion of independent directors on monitoring committees (Faleye et al., 2011), or the transition to an independent board (Benjamin et al., 2017).

However, little study has focused on the relevance of outside board members expertise in the corporations' major field to corporate innovation. In addition, the role as a consultant, rather than the role as a monitor, primarily uses an independent director's expertise.

The second literature stream explores the various factors that contribute to improving corporate performance in terms of innovation. Over the past decade, there has been a dramatic increase in the number of papers studying the topic of corporate innovation. Innovation is vital for national economic growth (Schumpeter, 1911) and can help build a corporation's long-term competitive advantage (Porter, 1992). Some studies argue that firm characteristics can enhance corporate innovation. For instance, firms embedded in alliance networks that exhibit both high clustering and high reach have greater innovative output than those without those characteristics (Schilling and Phelps, 2007). Firms that already have independent boards are predicted to have increased innovation activity overall (Benjamin et al., 2016).

Moreover, the existence of independent directors can have opposing effects on corporation, based on the roles they undertake. As consultants, Independent directors can provide diversified opinions and expertise to the management team (Benjamin et al., 2016), especially if the outside directors are university professors or experts in the field. Their suggestions and experience can inspire management teams to develop new ideas and put them into practice, increasing innovation activities. As monitors, independent directors can provide stronger control over the management team (Sitglitz and Weiss, 1983), therefore managers are under the pressure to produce decent outcome within a short period. These, managers would tend to pursue less exploratory projects to improve overall performance (Manso, 2011). R&D investments are typically long-term projects that can even hurt the short-term financial outcomes, the managers may be incentivized to reduce R&D

contributions. A board may resist exploring new areas if they find that the short-term stock market cannot properly reflect their investment in innovation (Cohen et al., 2013). As a result, corporate investments in actual innovation decrease.

These prior studies; however; may not be applicable to the unique setting of China. The effect of independent directors may have different effects in Chinese firms. Because Chinese patent law separates patents into the three categories of design patents, utility model patents, and technical invention patents, research on China must recognize theses categories. To be more specific, we should distinguish innovation activities into broad high-quality innovations and low-quality innovations. High-quality innovations contribute to improvements in technology and competitive advantages, while low-quality innovations take advantage of government subsidies or are introduced to comply with laws and regulations. Only high-quality innovations actually contribute to company development. Thus, we predict:

Hypothesis 1: Firms whose independent directors' expertise are of greater relevance to the firms' operational field will have more high-quality innovations.

Williamson (1975) describes an internal market mechanism in a multidivisional firm in which internal groups compete for the award of limited resources. Resources are defined as firm-specific physical, human, and organizational assets (Wernerfelt, 1984). Since R&D resources incorporate these three forms, they can be subject to a similar mechanism. According to the "resource leverage" view of Mathews (1997), since R&D resources are limited, innovation projects must compete against each other to obtain resources. We expect that firms offer incentives to concentrate on high-quality innovations; which reduces the physical and human resources allocated to lower-quality innovations.

Thus, the reallocation of innovative resources and the redeployment of human capital contribute to a refocusing of the scope of innovation (Alon et al., 2016). Moreover, when independent directors are acting as consultants, they can provide resources to conduct substantial research in the field. When a firm is granted access to resources, they will choose to conduct high-quality research instead of lower-quality research. Hence, we predict:

Hypothesis 2: Firms whose independent directors' expertise are of greater relevance to the firms' operational field will have fewer low-quality innovations.

3. Data and Measurement of Variables

3.1 Selection of Samples

Data from listed firms on the SSE and the SZSE in China from 2007 to 2017 were pooled and used in this study. We excluded corporations that are specially treated on the stock exchange because of poor performance, that have a negative equity or a negative fixed asset ratio, that have no directors, that have a negative number of years of listings, and that have an abnormal debt to asset ratio, i.e., smaller than or greater than 1. We winsorized the tails of the distribution at the 1% and 99% levels. In total, there were 721 corporations, and 5,123 observations used in the analyses. The data of patents, independent directors, and cooperate operational fields were collected from the China Stock Market and Accounting Research (CSMAR) database. Table 1 shows the raw data and the processed data categorized by type of industry. The proportions of each industry did not changed significantly from the raw data after the noise was excluded.

<Insert Table 1 here>

3.2 Measurement of Variables

In terms of dependent variables, innovation is highly abstract and subjective for companies and several recent papers have used patent data to quantify it (e.g., Amore et al., 2013; Brav et al., 2018; Donges et al., 2019). Some studies use R&D investment as a measure of innovation (e.g., Faleye et al., 2011; Manso, 2011; Simone et al., 2017; Chircop and Hass, 2018), but this measure cannot distinguish between high-quality and low-quality innovation. Others have used raw patent counts, together with the number of citations that a patent receives to measure the financial and technical value of innovation (Harhoff et al., 1999; Hall et al., 2005; Cerqueiro et al., 2015). Some have even looked at the classes of technology (Gonzalez-Uribe et al., 2017). To study innovation in China, this study assumes that design patents are more likely to be low-quality innovations because they do not make substantial changes in terms of technology; in contrast, technical invention patents are more likely to be high-quality innovations.

We thus measured the innovation ability of enterprises by the number of patent applications and the number of patent authorizations, distinguished into categories according to the degree of innovation, i.e., technical invention patents, utility model patents, and design patents. Given the large skewness of the absolute value of the number of patents, which cannot reflect the relative relationship of the three types patents, we instead measured the dependent variables by their proportion. The more technical invention patents an enterprise applies for, the more key technological achievements it has, and thus, the stronger its innovation ability. Therefore, to quantify corporate innovation, we use the proportion of technical invention patent applications, the proportion of utility model patent applications, and the proportion of design patent applications out of the total number of innovations. Then, to *qualify* corporate innovation, we use the proportion of technical invention patents *authorized*, the proportion of utility model patents authorized, and the proportion of design patents authorized out of the total number of innovations. Thus, we measure the motivation and strategies of corporate innovation from two aspects, i.e., the quantity and the quality.

As for key independent variables, we screened 867 technical independent directors by eliminating data of independent directors specializing in law and accounting.o determine whether the professional backgrounds and the research fields of independent directors match the main operational field of their corporation we reviewed sources such as resumes, annual reports, and firms' official websites. We thus set up a key independent variable, *Specialist*. If the independent directors' expertise field matched the corporate operational field, then *Specialist* equals 1, otherwise *Specialist* equals 0.

Referring to Balsmeier (2017), we defined control variables as those that might cause confusion in the relationship between the specialty of independent directors and enterprise innovation in terms of patent applications and authorizations. We found that there are significant differences in the proportion of R&D expenditure out of total expenses (*R&D*) and company size measured by total assets (*Size*) among the companies in our sample, and the two variables have a significant positive correlation with companies' innovation activities. The Tobin's Q value is often used as an important indicator to measure the performance or the growth of an enterprise. Therefore, we use *Tobin's Q* value to control the impact of the company's future growth potential on innovation activities. Since replacement costs are difficult to obtain, we referred to the method used by Wang (2003) and used the ending balance of total assets instead. In addition, we controlled for age (*Ln_Age*), the debt to asset ratio (*Leverage)*, the asset structure (*Tangibility*), the size of the board (*Boardsize*), and the proportion of independent directors in the board (*Indepboard*). In order to reduce the skewness of the numerical values, we took logarithms of those values. See Appendix 1 for the definitions of the variables.

Table 2 shows the descriptive statistics of the main variables. The mean of the key independent variable, *Specialist* is 0.615, indicating that 61.5% of the companies in manufacturing industries employed technical independent directors during the sample period. From the perspective of R&D input, the maximum value of R&D input of the listed companies in China is 21.9% and the minimum value is 1.12%. The sample standard deviation is 0.0112, which indicates that there is a significant difference between the ratio of R&D input and total assets of Chinese enterprises.

<Insert Table 2 here>

In terms of patent application, on average, the proportion of technical invention patent applications is higher than the proportion of other patent applications. The proportion of technical invention patent applications and that of utility model patent applications out of total number of patent applications are both around 0.4, while the proportion of design patent applications out of total number of patent applications is just 0.097. Besides, the number of technical invention patents authorized is significantly less than the number of technical invention patent applications, on average. In comparison, the proportion of utility model patents authorized, as well as the proportion of design patents authorized are much higher. In addition, the average listing years of corporations in the sample is 5.36 years, the average number of board members is 8.97, the average number of independent directors is 3, and the ratio of R&D expenditure to assets is 0.33%.

3.3 The Empirical Model

In creating the model, first, we verified the relationship between the relevance of independent directors' specialty and the firm’s technical invention patent application demonstrated in the line chart in Figure 1. The horizontal axis is the year, and the vertical axis is the average number of technical invention patent applications. As shown in Figure 1, when the independent directors’ specialty is relevant to the corporate operational field (*Specialist* equals 1), then the average number of technical invention patent applications is significantly higher than that when *Specialist* equals 0. This indicates that the relevance between independent directors’ expertise and the corporate operational field has a positive effect on the number of patent applications.

Figure 2 shows the relationship between the relevance of the independent directors' specialty and the number of corporate technical invention patent authorizations. The horizontal axis is year, and the vertical axis is the average number of invention patents granted. As shown in the graph, when the expertise of independent directors matches the corporations’ main business (i.e., *Specialist* equals 1), the average number of invention patent granted is significantly higher than that when *Specialist* equals 0. This indicates that the relevance between independent directors’ expertise and corporate operational field has a positive effect on the authorization of technical invention patents.

To discuss how the relevance of technical independent directors' expertise and corporate operational field influence corporate innovation, we refer to Balsmeier et al. (2017)and construct the following model using the ordinary least squares method:

$$Patent_{i,t+1} = \beta_0 + \beta_1 Specialist_{i,t} + controlled\ variables + \varepsilon_{it} \quad (1)$$

There are six indicators to measure how patents work in terms of quantity and quality, respectively. Given that innovation activities lag to some extent and referring to Atanassov (2013), we used one lagged patent data period (t + 1) to measure the impact of hiring technical independent directors in year t. The core explanatory variable, $Specialist_{i,t}$, measures whether the expertise fields of independent directors hired in year t match the main operational fields of the companies. Since fixed effects can eliminate the influence of unobserved variables that are constant with time, we adopt a two-way fixed effects model. The subscripts i and t represent the i^{th} firm and the t^{th} year respectively (t = 2007,…, 2017), γ_t is the fixed time effect, μ_t represents the fixed industry effect, X_{it} represent other control variables, and ε_{it} is the residual term. We use a heteroscedasticity robust standard error.

4. Summary Statistics

The regression results of Model 1 are shown in Table 3. The dependent variables in Columns 1–3 are three types of patent applications, namely the number of technical invention patent applications, the number of utility model patent applications, and the number of design patent applications. From the results, technical independent directors with expertise fields matching the corporate operational fields significantly increase the number of technical invention patent applications, with a coefficient of 0.09 at a significance level of 1%. The number of utility model patent applications is not significantly affected and there is a negative effect on the number of design patent applications, with a coefficient of −0.07 at a significance level of 1%. This shows that the participation of technical independent directors encourages enterprises to focus on high-quality technical invention patents rather than blindly pursue an improvement in the number of patents. Hence, the involvement of technical independent directors improves the innovation ability of enterprises.

<Insert Table 3 here>

The dependent variables in Columns 4–6 are the numbers of the three types of patents authorized: technical invention patents, utility model patents, and design patents. The coefficient of technical invention patents authorized is 0.10, and the coefficient of design patents authorized is −0.04; both are at a significance level of 1%. The absolute value of the coefficient of the technical invention patents authorized is greater than that of the technical invention patent applications, which indicates that the involvement of technical independent directors improves the quality of enterprise innovation. The results show that technical independent directors with expertise fields matching the corporate operational fields not only motivate companies to participate more in innovation activities, but also further improve the quality of invention patents.

In terms of control variables, Tobin's Q has a positive impact on both the technical invention patents authorized and corporate innovation, at a significance level of 10%. Tobin's Q has a negative impact on utility model patents and design patents. In terms of the number of patent applications, the coefficients of both utility model patents and design patents are −0.01. In terms of the number of patents authorized, the coefficient of design patents is −0.01, at a significance level of 1%. The results show that manufacturing enterprises with higher market value attach more importance to technical invention patents and pay less attention to other two types of patents. This conclusion is in accordance with the assumption that manufacturing industries generally attach more importance to technological innovations.

Given that independent directors may have a long-run impact on innovation performance, we further studied how the employment of relevant technical independent directors affects patents application in the subsequent three years. The assumption is that the number of patent applications is a better indicator of a firm's initiative than the number of patents authorized. Table 4 shows that after employing technical independent directors, corporations witness an increase in the number of technical invention patent applications and a reduction in the number of design patents in the following years, and this positive effect is greater with time. This implies that technical independent directors help more as consultants if they stay on board for a longer period.

<Insert Table 4 here>

5. Robustness Test

We examined the robustness of the cause-and-effect relationship between technical independent directors and enterprise innovation from two aspects. First, we used propensity score matching (PSM) to test the robustness of the benchmark model, and found that the test results are basically consistent with Table 5. Second, we used a placebo test to confirm that the significance we found is indeed due to the introduction of independent directors.

5.1 Endogeneity Problem: PSM Test

In order to reduce endogenous problems caused by sample selection bias and the influence of confounding variables, we used the PSM testing method and the variable $Specialist_{i,t}$ to conduct a logit regression on the control variable to get a propensity score. The regression result shows that the liability-to-asset ratio, the proportion of R&D expenditure, and the asset structure all have an impact on whether a company chooses to hire an independent director. Therefore, it is necessary to match according to the PSM method. We estimated a propensity score model and calculated the propensity score for each listed company. In addition, the nearest neighbor matching principle was applied to the one-to-one matching of each listed company. A total of 2,851 valid observations were finally obtained, applying to a total of 654 listed companies. In order to ensure the effectiveness of the PSM method, we carried out a balance test of the samples, and the results were satisfactory. The estimation results are shown in Table 5.

<Insert Table 5 here>

5.2 Placebo Test

To ensure that the significance is not simply due to random or accidental factors, we conducted a placebo test. We assumed that the matching of independent directors' specialty and corporate operational fields does not occur in the same year as the corporate innovation performance, but rather one year to three years in advance. The placebo results are shown in Table 6. They indicate that there is no significant change in the results after changing the timeline, thus the results are stable.

<Insert Table 6 here>

Understanding that the relations may still exist if the independent directors were of any profession, not just relevant technical fields, we conducted a further placebo test to ensure that when the variable *Specialist* is randomly selected, it does not have a processing effect on the technical invention patent applications. In doing so, we first disordered the variable *Specialist*, and randomly assigned each value of *Specialist* to each observation to generate a simulated explanatory variable *Random_Specialist*. We then regressed technical invention patent applications on *Random_Specialist* and recorded the regression results.

As shown in Figure 3, the t-statistic of the coefficient on *Random_Specialist* of 500 repeated samples is an inverted U-shape around 0. We then conducted a t-test and rejected the original hypothesis at a 1% significance level. We then regressed the other explanatory variables on *Random_Specialist*. The regression results and t-value descriptive statistic are shown in Table 7. We repeated the process 500 times, and the average of the coefficients of each explanatory variable are −0.000, −0.000, −0.002 and −0.000, respectively. The probabilities of the positive and negative regression coefficient beta are similar. Thus, the placebo test shows that the virtual processing effect we constructed does not exist. This means that the appointment of technical independent directors is the variable that promotes corporate innovation performance.

<Insert Table 7 here>

6. Further Analysis

6.1 Mechanism Test: R&D Expenditures

Next, we want to investigate the mechanism, i.e., *how* independent directors affect corporate innovation. Since more R&D expenditures can promote innovation performance, we studied whether the introduction of technical independent directors boosts R&D expenditures. We thus constructed a model as follows:

$$Patent_{i,t+1} = \beta_0 + \beta_1 Specialist_{i,t} + \beta_2 R\&D + \beta_3 Specialist_{i,t} \times R\&D + \alpha X_{it} + \gamma_t + \mu_i + \varepsilon_{it} \qquad (2)$$

The dependent variables are the proportion of technical invention patent applications, utility patent applications, and design patent applications out of the firms' total patent applications. The key explanatory variable is the product of *R&D* and *Specialist*. *R&D* is the proportion of R&D investment out of the total assets of a company. A larger *R&D* indicates that the company attaches greater importance to innovating activities. The other control variables remain unchanged. Table 8 shows the regression results of Model 2.

<Insert Table 8 here>

In Table 8, the product of *R&D* and *Specialist* is important; it represents the net effect of independent directors' expertise relevance on corporate innovation performance. The coefficient before *Invent-apply* is 3.81, at a significance level of 10%. This indicates that technical independent directors promote corporations to spend more on R&D. Meanwhile, the coefficients before *Utility-apply* and *Design-apply* are both negative and not significant. This implies that the introduction of technical independent directors steers corporate R&D activities, and thus innovation activities, which support our mechanism test.

6.2 R&D Quality

To measure the reliability of our indicators, we further analyzed the relationship between the introduction of technical independent directors and the patent citation rate, which indicates recognition of the innovation. We followed Balsmeier et al. (2017) and Lanjouw and Schankerman (2004), using multiple patent indicators to describe the quality of innovation in addition to patent application and authorization.

We changed the independent variables in Model 1 to *Patent Citation* and *Self-Citation*, as follows:

Patent Citation measures the patent's position in the distribution of the citation relative to other granted patents within the same patent category and in the same year. Based on how often patents are cited, the degree of innovation recognition can be categorized into the top 1% of patents, the top 2%–10% of patents, patents that are not in the top 10% but have been cited at least once, and patents that have never been cited. If a patent falls in the top 1% or the top 2%–10% of patents, it is in the highest percentile of the citation distribution among patents in the same patent category in the same year. To further measure whether technical independent directors can improve corporate innovation's quality, we selected the top 1% patents and the top 2–10% patents as the indicators.

Self-Citation measures the times a company cites other patents within the same corporation. Following Faleye and Hoitash (2011), more self-citations indicate that a corporation is digging into the current field; fewer self-citations suggest that the corporation is expanding their research scope or exploring new fields.

Table 9 represents the results of patents with citations in the top 1%, the top 2%–10%, and self-citations, respectively. As shown in the results, the coefficient of patents whose citation is in the top 1% is 0.05, significant at the level of 10%; the coefficient of patents whose citation is between the top 2% and 10% is 0.11 and is significant at the level of 5%.

Thus, we can conclude that the introduction of technical independent directors promotes high-quality innovation in the company. Moreover, the coefficient of self-citation is positive and statistically significant, suggesting that corporations mainly dig into their current research field rather expanding their research scope. In this respect, technical independent directors can further promote corporate innovation in their operational fields.

<Insert Table 9 here>

7. Conclusions

To summarize, we studied the A-share listed corporations of the SSE and SZSE in China from 2007 to 2017 and found that specialists can play a consulting role better when their fields of expertise are more relevant to the corporations' operational field. Thus, we help provide empirical evidence to encourage enterprises to hire relevant scholars as independent directors. Furthermore, technical independent directors can utilize their expertise to help public companies with technical innovations, which could contribute to industrial and economic growth in general.

This paper not only enriches and develops the existing literature on the capital market but also provides a new perspective for research on the consulting function of independent directors. In our further analysis, we took a closer view at the mechanism for independent directors in enhancing corporate innovation. We found that they increase research and development deeper in the corporations' current research field rather than expanding in other relevant fields. Thus, if corporations are adopting a differentiation strategy and want to expand to other fields, they need to carefully consider the involvement of technical independent directors.

This paper can help guide policy making and practical application in the following ways: first, it encourages the government to conduct research before releasing policy changes to evaluate the difficulty of corporate innovations, according to the relevance of technical specialist expertise and corporate operational fields. Second, enterprises should make full use of independent directors who truly participate in corporate governance and innovation and promote industrial transformation. Third, when hiring university professors as technical independent directors, enterprises should give priority to hiring those whose expertise is consistent with their own main business to promote substantial innovation and sustainable and healthy economic development.

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Appendix 1: Variable Definitions

This table presents the definition of all the variables used in our models, including dependent variables, independent variables, and control variables.

Variables	Abbreviation	Definition and measurement
Dependent variables	Invent-apply	Number of technical invention patents applications out of total number of patents applied
	Utility-apply	Number of utility model patents applied out of total number of patents applied
	Design-apply	Number of design patents applied out of total number of patents applied
	Invent-grant	Number of technical invention patents authorized out of total number of patents authorized
	Utility-grant	Number of utility model patents authorized out of total number of patents authorized
	Design-grant	Number of design patents authorized out of total number of patents authorized
Independent variables	Specialist	Dummy variable： if independent directors’ expertise field matches the corporate operational field, then Specialist = 1, otherwise Specialist = 0.
Control variables	Ln_Size	Logarithm of total asset
	Ln_Age	Logarithm of corporate trading years starting from the IPO
	Leverage	Total liability out of taxed asset
	Tangibility	Carrying value of fixed asset out of total asset
	Tobin’s Q	Tobin’s Q = market capitalization out of asset replacement cost
	R&D	R&D expenses out of total assets
	Boardsize	Logarithm of number of directors
	Indepboard	Number of independent directors out of total number of directors

Appendix 2: Independent directors' specialty and corporate innovation

Figure 1 shows the relationship between the relevance of independent directors' specialty and the corporate technical invention patent application. The x-axis represents years, and the y-axis is the number of technical innovation patents application. The blue line represents it when the independent directors’ expertise is relevant to the dorporate trading field. Otherwise it is represented in the red line. Figure 2 shows the relationship between the relevance of independent directors' specialty and the corporate technical invention patent authorization. The x-axis represents years, and the y-axis is the number of technical innovation patents authorization. The blue line represents it when the independent directors’ expertise is relevant to the dorporate trading field. Otherwise it is represented in the red line.

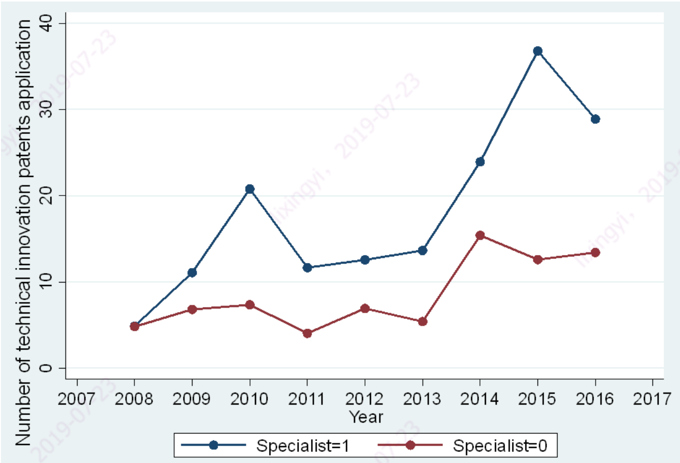

Figure 1: Relevance of independent directors' specialty and patents application

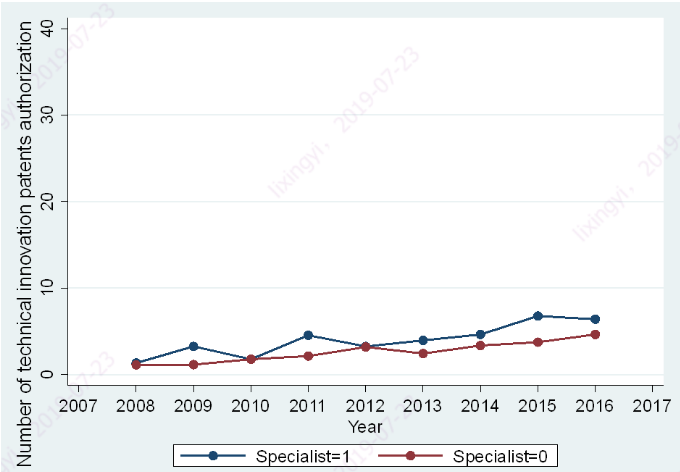

Figure 2: Relevance of independent directors' specialty and patens authorization

Table 1

Variable assignment of manufacturing industries

This table represents the raw data we collected from the CSMAR database, and the processed data categorized by industries and excluded the noises. We chose specifically the corporations from the manufacturing industries, i.e., category C in the database. And we calculated the frequencies, relative frequencies, and cumulative percentage of each industry.

CSMAR Category C	**Raw Data**			**Processed Data**		
Manufacturing Industry	Frequency	Percentage	Cumulative Percentage	Frequency	Percentage	Cumulative Percentage
Special equipment manufacturer	1,311	7.80	7.80	232	8.52	8.52
Instrument manufacturer	269	1.60	9.40	37	1.36	9.88
Other manufacturer	136	0.81	10.21	8	0.29	10.17
Agricultural and sideline food processor	358	2.13	12.34	71	2.61	12.78
Chemicals Manufacturer	1,682	10.00	22.34	246	9.03	21.81
Chemical fiber manufacturer	205	1.22	23.56	20	0.73	22.54
Pharmaceutical manufacturer	1,741	10.36	33.91	313	11.49	34.03
Printing and recording media reproduction	61	0.36	34.28			
Furniture manufacturer	70	0.42	34.69	12	0.44	34.47
Waste resources recycling	57	0.34	35.03			
Education, recreation, and sports supplies manufacturer	80	0.48	35.51	11	0.40	34.88
Nonferrous metal smelting and rolling processor	741	4.41	39.92	132	4.85	39.72
wood, bamboo, rattan, palm, grass products manufacturer	86	0.51	40.43	3	0.11	39.83
Rubber and plastic products manufacturer	480	2.85	43.28	85	3.12	42.95
Car manufacturer	804	4.78	48.06	103	3.78	46.73
Electrical machinery and equipment manufacturer	1,562	9.29	57.35	309	11.34	58.08
Leather, fur, feather products manufacturer	32	0.19	57.54	1	0.04	58.11
Petroleum processor, coking and nuclear fuel processor	195	1.16	58.70	27	0.99	59.10
Textile industry	438	2.61	61.31	80	2.94	62.04
Clothing industry	231	1.37	62.68	42	1.54	63.58
Computers, and other electronic equipment manufacturer	2,275	13.53	76.21	419	15.38	78.96
General equipment manufacturer	1,016	6.04	82.26	167	6.13	85.10
Paper products manufacturer	234	1.39	83.65	33	1.21	86.31

Wine, beverage and refined tea manufacturer	435	2.59	86.24	69	2.53	88.84
Metal products manufacturer	405	2.41	88.65	53	1.95	90.79
Transporting equipment manufacturer	468	2.78	91.43	71	2.61	93.39
Non-metallic mineral products manufacturer	701	4.17	95.60	97	3.56	96.95
Food industry	249	1.48	97.08	48	1.76	98.72
Ferrous metal industry	491	2.92	100.00	35	1.28	100.0
Total	16,813	100.00		2724	100.00	

Table 2

Descriptive statistics of variables

The sample consists of 721 firms with financial and patent data available from the CSMAR database. Patents are divided into three categories according to the degree of innovation, i.e. technical invention patents, utility model patents, and design patents. And we calculated the proportion of each category in the patent data, distinguishing between authorization and application, defining them as *Ratio_Iapply* , *Ratio_Uapply* , *Ratio_Dapply* , *Ratio_Igrant* , *Ratio_Ugrant* and *Ratio_Ugrant*. *Specialist* is the key dummy variable. If expertise field of independent directors hired by the company in this year matches the corporate trading field, then *Specialist* = 1, otherwise *Specialist* = 0. *Ln_Size* is computed as logarithm of total asset. *Ln_Age* is computed as logarithm of corporate trading years starting from the IPO. *Leverage* is computed as Total liability divided by tax asset. *Tangibility* is computed as Carrying value of fixed asset divided by total asset. *Tobin's Q* is computed as market capitalization divided by asset replacement cost. *R&D* is computed as R&D expenses divided by total assets. *Boardsize* is computed as Number of directors. *Indepboard* is computed as Number of independent directors. Control variables are winsorized at the 1st and 99th percentiles.

Variable	Sample size	mean	Std dev	max	min
Invent-apply	5123	0.473	0.348	0	1
Utility-apply	5123	0.43	0.337	0	1
Design-apply	5123	0.097	0.228	0	1
Invent-grant	4773	0.351	0.386	0	1
Utility-grant	4773	0.537	0.395	0	1
Design-grant	4773	0.112	0.252	0	1
Specialist	5123	0.615	0.487	0	1
Ln_Size	5123	21.97	1.267	19.17	28.00
Ln_Age	3971	1.551	0.763	0	2.833
Tangibility	5105	0.182	0.143	0	0.852
Tobin's Q	4993	2.584	2.155	0.113	24.94
R&D	3147	0.00325	0.0112	0	0.219
Boardsize	5106	8.969	1.811	3	18
Indepboard	5107	3.293	0.632	1	8
Ratio_Iapply	5123	0.473	0.348	0	1

Table 3

Technical independent directors and corporate innovation：basic results

This table presents panel regression model (1) estimates of patent classified by the degree of innovation from 2007 to 2017 as a function of *Specialist*. We used the patent data of (t+1) period to measure the impact of hiring technical independent directors in the year t. *Specialist* measures whether the expertise fields of independent directors hired in year t match the main operational fields of the companies. The firm characteristics employed as control variables are the same as those in Appendix 1. The control variables and patents are winsorized at the 1st and 99th percentiles, whose data are available from *CSMAR* database. we adopt the two-way fixed effect model to analysis. t statistics are presented in parentheses. ***, **,and * indicate that the parameter estimate is significantly different from zero at the 1%, 5%, and10% level, respectively.

	(1)Invent-apply	(2)Utility-apply	(3)Design-apply	(4)Invent-grant	(5)Utility-grant	(6)Design-grant
Specialist	0.09***	-0.02	-0.07***	0.10***	-0.06*	-0.04**
	(3.00)	(-0.79)	(-3.23)	(3.33)	(-1.82)	(-2.14)
Tangibility	-0.02	-0.01	0.02	-0.19*	0.17*	0.01
	(-0.20)	(-0.12)	(0.51)	(-1.96)	(1.87)	(0.23)
ln_Age	0.09**	-0.10**	0.01	0.12**	-0.13***	0.01
	(1.97)	(-2.44)	(0.30)	(2.47)	(-2.76)	(0.42)
ln_Size	0.04**	-0.03**	-0.01	0.01	0.02	-0.03***
	(2.51)	(-2.32)	(-1.17)	(0.34)	(1.50)	(-3.00)
Leverage	0.02	-0.02	0.00	0.08	-0.09	0.01
	(0.21)	(-0.28)	(0.04)	(0.87)	(-1.05)	(0.26)
R&D	-0.28	0.22	0.06	0.23	0.08	-0.31
	(-0.60)	(0.61)	(0.21)	(0.51)	(0.18)	(-1.00)
Tobin's Q	0.01*	-0.01	-0.01	0.02**	-0.01	-0.01***
	(1.70)	(-1.08)	(-1.31)	(2.13)	(-0.68)	(-3.05)
Indepboard	-0.44**	0.02	0.41***	-0.12	-0.30	0.42**
	(-1.98)	(0.12)	(2.96)	(-0.42)	(-0.99)	(2.38)
Boardsize	-0.02***	0.02**	0.01	-0.01	-0.00	0.01**
	(-2.87)	(2.47)	(1.39)	(-1.38)	(-0.17)	(2.50)
_Cons	-0.30	1.19***	0.11	-0.07	0.65*	0.42**

	(-0.95)	(4.40)	(0.64)	(-0.20)	(1.82)	(2.02)
N	1606	1606	1606	1583	1583	1583
Adj.R^2	0.23	0.29	0.11	0.21	0.25	0.13
F	3.88	2.31	3.22	3.96	1.94	3.98

Table 4

Technical independent directors and corporate innovation: long-term effect

This table presents regression estimates of patent classified by the degree of innovation from 2007 to 2017 as a function of Specialist in the long run. We used the patent data to measure the impact of hiring technical independent directors in the year t+2, t+3 and t+4, respectively. *Specialist* measures whether the expertise fields of independent directors hired in year t match the main operational fields of the companies. The firm characteristics employed as control variables are the same as those in Appendix 1. The control variables and patents are winsorized at the 1st and 99th percentiles, whose data are available from CSMAR database. We adopt the two-way fixed effect model to analysis. Except when otherwise indicated, numbers in parentheses are t statistics, clustered at the firm level. ***,**, and * indicate that the parameter estimate is significantly different from zero at the 1%, 5%,and 10% level, respectively.

	(1)Invent-apply $_{t+2}$	(2)Design -apply $_{t+2}$	(1)Invent-apply $_{t+3}$	(2)Design -apply $_{t+3}$	(1)Invent-apply $_{t+4}$	(2)Design -apply $_{t+4}$
Specialist	0.10**	-0.07***	0.13***	-0.08***	0.14***	-0.08**
	(2.42)	(-3.03)	(3.01)	(-2.83)	(2.65)	(-2.05)
Tangibility	0.05	0.03	-0.09	0.05	0.04	0.11
	(0.50)	(0.78)	(-0.74)	(0.72)	(0.20)	(1.34)
ln_Age	0.13**	0.03	0.13*	0.03	0.20**	0.02
	(2.30)	(1.19)	(1.79)	(0.91)	(2.16)	(0.44)
ln_Size	0.04**	-0.01	0.05**	-0.01	0.04	-0.02
	(2.33)	(-1.34)	(2.52)	(-1.48)	(1.48)	(-1.21)
Leverage	0.09	-0.01	0.13	-0.00	-0.11	0.08
	(0.92)	(-0.23)	(1.17)	(-0.04)	(-0.65)	(0.87)
R&D	-0.31	-0.09	-0.86	-0.29	-0.23	-0.18
	(-0.55)	(-0.36)	(-1.21)	(-1.56)	(-0.31)	(-0.59)
Tobin's Q	0.01	-0.01	0.02	-0.01*	-0.02	-0.00
	(0.83)	(-1.30)	(1.12)	(-1.89)	(-0.99)	(-0.60)
Indepboard	-0.26	0.31	0.19	-0.14	0.06	-0.20
	(-0.85)	(1.49)	(0.50)	(-0.48)	(0.10)	(-0.64)
Boardsize	-0.03**	0.00	-0.02	-0.01	-0.02	-0.01
	(-2.41)	(0.44)	(-1.24)	(-1.14)	(-1.28)	(-1.05)

_cons	-0.57	0.15	-1.02**	0.50*	-0.81	0.55
	(-1.34)	(0.67)	(-2.01)	(1.82)	(-1.22)	(1.48)
N	885	885	575	575	339	339
r2	0.28	0.18	0.24	0.20	0.31	0.35
F	4.05	2.77	3.59	2.33	2.34	1.13

Table 5

Technical independent directors and corporate innovation: PSM results

This table presents PSM regression estimates of patent classified by the degree of innovation from 2007 to 2017 as a function of *Specialist*. We used the patent data of (t+1) period to measure the impact of hiring technical independent directors in the year t. *Specialist* was used to conduct logit regression on the control variable to get the propensity score. We estimated the propensity score model and calculated the propensity score of each listed company. The nearest neighbor matching principle was applied to the one-to-one matching of each listed company, and 2,851 valid observations were finally obtained, which is a total of 654 listed companies. The firm characteristics employed as control variables are the same as those in Appendix 1. The control variables and patents are winsorized at the 1st and 99th percentiles, whose data are available from CSMAR database. We adopt the two-way fixed effect model to analysis. t statistics are presented in parentheses. ***, **,and * indicate that the parameter estimate is significantly different from zero at the 1%, 5%, and10% level, respectively.

	(1)Invent-apply	(2)Utility-apply	(3)Design-apply	(4)Invent-grant	(5)Utility-grant	(6)Design-grant
Specialist	0.11***	-0.02	-0.09***	0.10**	-0.01	-0.09***
	(3.20)	(-0.54)	(-3.30)	(2.59)	(-0.22)	(-3.08)
Tangibility	-0.02	0.05	-0.02	-0.16	0.24**	-0.08
	(-0.25)	(0.52)	(-0.34)	(-1.42)	(2.25)	(-1.25)
Ln_Age	0.06	-0.07	0.01	0.10*	-0.10*	-0.00
	(1.21)	(-1.56)	(0.27)	(1.83)	(-1.80)	(-0.04)
Ln_Size	0.04**	-0.03**	-0.00	0.01	0.01	-0.03**
	(1.99)	(-2.27)	(-0.26)	(0.69)	(0.94)	(-2.34)
Leverage	-0.01	-0.06	0.07	0.06	-0.08	0.02
	(-0.08)	(-0.80)	(1.17)	(0.51)	(-0.75)	(0.35)
R&D	-0.20	0.62	-0.43	0.86	-0.38	-0.48
	(-0.29)	(1.01)	(-1.15)	(1.55)	(-0.59)	(-1.03)
Tobin's Q	0.01	-0.01*	-0.00	0.01	-0.00	-0.01**
	(1.63)	(-1.80)	(-0.07)	(1.33)	(-0.19)	(-1.99)
Indepboard	-0.61**	0.22	0.40**	-0.08	-0.46	0.54**
	(-2.29)	(0.84)	(2.22)	(-0.26)	(-1.61)	(2.37)
Boardsize	-0.02**	0.02**	-0.00	-0.01	-0.01	0.02**

	(-2.39)	(2.52)	(-0.08)	(-0.54)	(-0.91)	(2.18)
_Cons	-0.14	1.12***	0.02	-0.21	0.75**	0.46*
	(-0.36)	(3.34)	(0.09)	(-0.53)	(1.97)	(1.68)
N	837	837	837	799	799	799
R^2	0.27	0.31	0.15	0.26	0.31	0.19
F	3.28	1.79	3.11	2.51	1.24	3.04

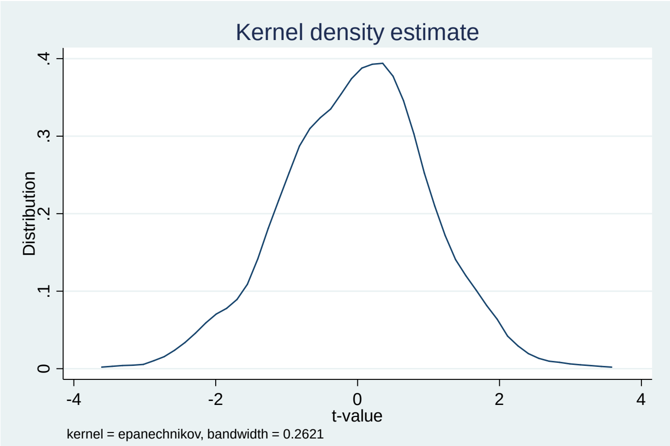

Figure 3: Kernal density estimate of technical invention patents application number

Figure 3 shows the Kernal density estimate of technical invention patents application number t-statistic. It shows the coefficient on Random_Specialist of 500 repeated samples.

Table 6

Technical independent directors and corporate innovation: Placebo test

This table presents placebo-test regression estimates of patent classified by the degree of innovation from 2007 to 2017 as a function of *Specialist* from the precious period. We used the patent data of t period to measure the impact of hiring technical independent directors in the year t. *Specialist t-1* assumes that the expertise fields of independent directors hired in year t-1 match the main operational fields of the companies. *Specialist t-2* assumes that the expertise fields of independent directors hired in year t-2 match the main operational fields of the companies. *Specialist t-3* assumes that the expertise fields of independent directors hired in year t-3 match the main operational fields of the companies. The firm characteristics employed as control variables are the same as those in Appendix 1. The control variables and patents are winsorized at the 1st and 99th percentiles, whose data are available from *CSMAR* database. We adopt the two-way fixed effect model to analysis. t statistics are presented in parentheses. ***, **,and * indicate that the parameter estimate is significantly different from zero at the 1%, 5%, and10% level, respectively.

	(1)Invent-apply	(2)Utility-apply	(3)Design-apply	(4)Invent-grant	(5)Utility-grant	(6)Design-grant
Specialist $_{t-1}$	0.02	-0.00	-0.02	0.04	0.03	-0.07
	(0.46)	(-0.01)	(-0.43)	(0.69)	(0.61)	(-1.26)
Specialist $_{t-2}$	-0.04	-0.03	0.07	-0.13*	0.12*	0.01
	(-0.71)	(-0.30)	(1.16)	(-1.69)	(1.81)	(0.17)
Specialist $_{t-3}$	-0.10	0.11	-0.01	0.02	0.08	-0.10
	(-1.38)	(1.19)	(-0.11)	(0.14)	(0.91)	(-0.87)
Control variable	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Fixed effects	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled

Table 7
Placebo test (500 repeated sampling)

This table presents 500 repeated sampling model (1) regression estimates of patent classified by the degree of innovation from 2007 to 2017 as a function of *Specialist*. The key explanatory variable, *Specialist*, in the sample was randomly assigned to each observation based on a retractable (repeatable) sampling. For each sample, the estimated coefficient of$\boldsymbol{\beta_1}$ and its t-value are recorded. In Table 6, Mean beta for *Random_Specialist* reports descriptive statistical results of estimated coefficient$\boldsymbol{\beta_1}$ of the simulated explanatory variables (column names are explanatory variables). In square brackets, the probability that the estimated coefficient$\boldsymbol{\beta_1}$ is significantly positive [% β>0 & α<5%] or significantly negative [% β>0 & α<5%] at 5% significance level is reported successively. In the regression, we cluster the data by firms according to the stock codes and use robust regression to deal with heteroskedasticity.

Variables	Invent-apply	Design-apply	Invent-grant	Design-grant
Regression $\boldsymbol{\beta_1}$	0.09***	-0.07***	0.10***	-0.04**
t-test	pvalue=0.000***	pvalue=0.000***	pvalue=0.000***	pvalue=0.000***
Mean $\boldsymbol{\beta_1}$ for *Random_Specialist*	0.000	0.000	0.002	0.000
[% β>0 & α≤5%; % β<0 & α≤5%]	[2.2%; 3.2%]	[4.6%; 1.4%]	[3.4%; 2%]	[3.8%; 3%]
[% β>0 & α≤1%; % β<0 & α≤1%]	[0.6%; 0.4%]	[1.6%; 0.2%]	[0.8%; 0.4%]	[0.8%; 0.2%]

Table 8

Technical independent directors and corporate innovation: Mechanism test

This table presents panel regression model (2) estimates of application patent from 2007 to 2017 as a function of Specialist and R&D. The dependent variables are the proportion of technical invention patents applied, utility patents applied, and design patents applied out of total patents applied in (t+1) period. *R&D* refers to the proportion of R&D investment out of the total assets of a company. *Specialist* measures whether the expertise fields of independent directors hired in year t match the main operational fields of the companies. The key explanatory variable is the product of R&D and Specialist.. The firm characteristics employed as control variables are the same as those in Appendix 1. The control variables and patents are winsorized at the 1st and 99th percentiles, whose data are available from CSMAR database. We adopt the two-way fixed effect model to analysis. t statistics are in parentheses. ***, **,and * indicate that the parameter estimate is significantly different from zero at the 1%, 5%, and10% level, respectively.

	(1) Invent-apply	(2) Utility-apply	(3) Design-apply
R&D*Specialist	3.81*	-2.12	-1.69
	(1.79)	(-0.80)	(-0.57)
Specialist	0.08**	-0.00	-0.07***
	(2.21)	(-0.12)	(-2.78)
R&D	-3.79*	2.40	1.38
	(-1.88)	(0.94)	(0.47)
Tangibility	-0.00	0.03	-0.03
	(-0.02)	(0.42)	(-0.61)
ln_Age	0.06	-0.05	-0.01
	(1.17)	(-1.13)	(-0.24)
ln_Size	0.03**	-0.03**	-0.01
	(1.97)	(-1.99)	(-0.60)
Leverage	0.00	-0.05	0.05
	(0.01)	(-0.71)	(0.90)
Tobin's Q	0.02**	-0.01	-0.00
	(1.97)	(-1.59)	(-0.83)
Indepboard	-0.58**	0.15	0.43**

	(-2.24)	(0.59)	(2.51)
Boardsize	-0.02*	0.02*	0.00
	(-1.89)	(1.91)	(0.17)
_Cons	-0.13	1.00***	0.12
	(-0.34)	(3.16)	(0.53)
N	939	939	939
R2	0.29	0.34	0.17
F	3.63	1.23	2.80

Table 9

Technical independent directors and corporate innovation: R&D quality

This table presents regression estimates of patent citation and self-citation from 2007 to 2017 as a function of Specialist. *Top1* represents the 1% position of the patent in the distribution of citation relative to other granted patents within the same patent category and the same year. *Top2_10* represents the 2%-10% position of the patent in the distribution of citation relative to other granted patents within the same patent category and the same year. *Self_cited* represents the times that a company cites some other patents within the same corporation. We used these patent data of (t+1) period to measure the impact of hiring technical independent directors in the year t. *Specialist* t measures whether the expertise fields of independent directors hired in year t match the main operational fields of the companies. The firm characteristics employed as control variables are the same as those in Appendix 1. The control variables and patents are winsorized at the 1st and 99th percentiles, whose data are available from *CSMAR* database. we adopt the two-way fixed effect model to analysis. t statistics are presented in parentheses. ***, **,and * indicate that the parameter estimate is significantly different from zero at the 1%, 5%, and10% level, respectively.

	(1) Top1	(2) Top2_10	(3) Self_cited
Specialist	0.05*	0.11**	0.24**
	(1.71)	(2.14)	(2.21)
Tangibility	0.08	-0.00	-0.05
	(0.62)	(-0.01)	(-0.12)
Ln_Age	-0.00	0.00	0.00
	(-0.64)	(0.77)	(0.15)
Ln_Size	0.08**	0.08***	0.22***
	(2.33)	(2.72)	(3.36)
Leverage	-0.00	-0.08	0.09
	(-0.02)	(-0.63)	(0.32)
R&d	3.05	1.84	9.15**
	(1.46)	(1.18)	(2.00)
Tobin's Q	0.02	0.01	0.03
	(1.57)	(1.14)	(1.34)
Indepboard	0.17	0.85**	1.76
	(0.57)	(2.17)	(1.63)

Boardsize	-0.01	0.00	0.08
	(-1.40)	(0.13)	(1.64)
_Cons	-1.76**	-1.91***	-5.70***
	(-2.09)	(-2.93)	(-3.87)
N	831	831	831
R2	0.3022	0.4030	0.3281
F	1.5666	2.3197	3.5099