

Rising to the challenge: Top executives with R&D background, risk-taking, and corporate innovation

Abstract: More than half of Chinese high-technology firms are led by top executives (chairman and CEO) with R&D background. This study investigates whether and how top executives' R&D background affects corporate innovation outcomes using a sample of listed firms in the high-technology industries in China. We find that the R&D background of top executives is positively related to innovation outcomes. We also find evidence on the mediating effect of R&D expenditure and moderating effect of corporate risk-taking on the above relationship. Our baseline results are robust to tests that address concerns caused by potential unobservable characteristics, reverse causality, and other issues. Findings of our study have important implications for firms that aim to enhance their innovation outcomes and countries regarding their research policymaking and R&D management.

Keywords: top executives, R&D background, innovation outcomes, R&D expenditure, risk-taking

1. Introduction

A CEO's research orientation is a good indicator of a company's motivation to innovate and ultimately affects innovation outcomes. Research-centric CEOs create the organisational conditions to foster innovation like supporting research-oriented managers to innovate, increase their managerial discretion and allocate more resources to R&D. This, in turn, helps innovation thrive.

-- Forbes Nov 19, 2019

Extant literature has studied the effect on firms' innovation outcomes of various CEO characteristics, such as military experience (Benmelech and Frydman, 2015), pilot CEOs (Sunder et al., 2017), inventor CEOs (Islam and Zein, 2020), and technical backgrounds (Daellenbach et al., 1999; Barker and Mueller, 2002). However, one important area that has received little attention is top executives' R&D background.¹ This lack is surprising given that top executives' R&D background enables firms to make effective innovation strategy choices in the first place (Ahuja and Lampert, 2001; Omar, Mohan, & Zhao, 2017). It is also a good indicator of a company's critical organisational conditions in which innovation capabilities reside (Talke et al., 2010; Amyx, 2019; van de Wal et al. 2020). This paper aims to investigate whether and how CEO's R&D background affects corporate innovation outcomes using a sample of high-technology firms in China.

The first reason of focusing on high-technology firms is that innovation activities are crucial for survival in high-technology industries. Competition in these industries is knowledge-based and our study of top executives' background, experience, and

knowledge on R&D, therefore, provides a good understanding of one of the major sources of competition (Yun, Yang, & Park, 2016). Second, compared with other industries where the R&D function is often outsourced (Chesbrough,2003; Chesbrough and Crowther, 2006), high-technology industries have seen the majority of R&D activities being internally conducted, which provides a context where the mediating effect of R&D investments on the relationship between top executives' R&D background and innovation outcomes can be investigated. Third, although firms in high-technology industries tend to involve in more innovation activities than those in other industries, not all high-technology firms are equally innovative. It is therefore important to understand factors that are supportive of corporate innovation within this population of firms (Hayton, 2005).

The rationale of using China as a laboratory to investigate the effect of CEO with R&D background on corporate innovation is two-fold. First, China, which has been well-known as the world's manufacturing center, also emerges as a global innovation leader.² For example, according to the data from the World Intellectual Property Organisation (WIPO)'s Patent Cooperation Treaty (PCT) System, China filed 58,990 applications in 2019, which surpassed the U.S. (57,840 applications in 2019) as the biggest filer of international patents – a position previously held by the U.S. each year since the PCT began operations in 1978.³ Moreover, the PCT applicant list in China largely comprises organisations from the corporate sector and the PCT Top Ten Applicants are all companies.⁴ Second, as opposed to many other countries, including the US where CEOs of big pharmaceutical giants, for example, are more likely to have

a background as company lawyers, salespeople, or finance managers, than one in pharmaceutical or medicine R&D (Felix and Bistrova, 2015), more than half of our sample high-technology companies in China are led by top executives (CEO and/or Chairman) with R&D background. This provides a sound context where the effect of CEO with R&D background on corporate innovation is investigated.

Using a sample of listed firms in the high-technology industries in China over the period from 2012 to 2017⁵, we investigate whether and how top executives' R&D background affects corporate innovation outcomes. We find that the R&D background of top executives is positively related to innovation outcomes. We also find evidence on the mediating effect of R&D expenditure and moderating effect of corporate risk-taking on the above relationship.

The positive correlation between top executives' R&D background and innovation outcomes, however, needs to be interpreted with caution. The observed positive correlation could be caused by unobservable variables that may also explain innovation outcomes. One way to address such a concern is to analyse variations among firms led by top executives with R&D background only. If top executives' R&D background does indeed drive the above positive correlation, then this effect should be stronger for top executives with longer R&D experience. Our results show that the longer the R&D experience of top executives is, the better the innovation outcomes. Our observed positive correlation could also be caused by potential reverse causality in that firms pursuing innovation strategies and outcomes may be more likely to select top executives with R&D background (Chaganti and Sambharya, 1987; Thomas et al., 1991;

Datta and Guthrie, 1994). To address this concern, we employ the propensity score matching (PSM) method, which shows that our baseline results are robust.

The contribution of this study to the literature is three-fold. First, this paper answers the call for studies on mechanisms behind China's innovation achievements at the firm-level (Wang et al., 2014; Xiong and Xia, 2020). Second, this paper builds upon the earlier studies that investigate the effect on firms' innovation outcomes of various CEO characteristics. Our paper is complementary to those studies by examining the impact of top executives' R&D background, which is an important but yet underexplored characteristic of top executives. Two studies closest to our study are the Islam and Zein (2020) study examining the impact of 'inventor CEOs' on corporate innovation and van de Wal et al. (2020) study looking into the impact of CEO research orientation on firm innovation outcomes. Islam and Zein (2020) find a causal relationship that 'inventor CEOs' contribute to higher quality corporate innovation. Given that inventor CEOs may not be prevalent everywhere, our study complements the Islam and Zein (2020) study by examining the impact on corporate innovation of R&D background of top executives, which is a broader and more prevalent phenomenon and of which the findings are more generalisable. van de Wal et al. (2020), which uses 109 CEOs from 87 U.S.-based pharmaceutical firms over the period 2001–2013 as a sample, find that research-oriented CEOs increase their firms' innovation outcomes. Our study complements the van de Wal et al. (2020) study by focusing on all high-technology industries. Third, this study not only reveals the association between top executives' R&D background and corporate innovation outcomes, but also further

attempts to explore the underlying mechanisms and moderating factors, which contributes to a comprehensive understanding on the relationship between top executives' R&D background and innovation outcomes.

The remainder of this paper is organised as follows. Section 2 presents the literature review and hypothesis development. Research design and empirical results are discussed in Section 3 and 4, respectively. Section 5 concludes the paper and makes some discussions.

2. Literature review and hypothesis development

2.1 Literature review

A growing body of literature has related various CEO characteristics to innovation or R&D spending, but considerably limited attention has been put on CEO R&D background which is an important aspect of a CEO's personal characteristics that may influence corporate innovation strategies and performance (Islam and Zein, 2020).

Some earlier studies that close to our study have connected R&D background of top management team (TMT) to innovation strategies, but these studies have focused on the other way around, i.e., the impact of innovation strategies on TMTs' R&D background. For example, Chaganti and Sambharya (1987) find that firms following the product innovation strategy tend to have a higher proportion of TMTs with production and R&D backgrounds and lower proportion of TMTs with financial backgrounds. Thomas et al. (1991) also find that firms following market innovation strategies are more likely to be led by CEOs who have marketing or R&D functional

backgrounds. Datta and Guthrie (1994) study CEO successions and find that firms with higher R&D spending are more likely to appoint new CEOs who have technical backgrounds.

Some other studies have examined the impact of the technical or other backgrounds of the TMT or CEO on innovation commitment. For example, Daellenbach et al. (1999) relate the technical orientation of the TMT or CEO and R&D intensity and find that the proportion of a firm's top managers with working experience in technical areas (namely, engineering, production or operations, or R&D) are positively related to the firm's commitment to innovation. Barker and Mueller (2002) find that firms where CEOs have significant working experience in marketing, engineering, or R&D tend to have greater R&D spending. While these two studies attempt to explore the impact of TMT technical backgrounds and provide a theoretical base for our study, they have focused on the impact of broad TMT backgrounds that cover engineering, production, operations, marketing, or R&D and failed to lay a solid theoretical foundation and explore the mechanisms underpinning the impact of each background. Another limitation of the above studies is that they only focus on the impact of the technical or other backgrounds of the TMT or CEO on R&D spending, which makes them unable to reveal the impact of TMT backgrounds on innovation outcomes.

Two studies closest to our study are the Islam and Zein (2020) study and van de Wal et al. (2020) study. Islam and Zein (2020) examine the impact of 'inventor CEOs' on corporate innovation and find that 'inventor CEOs' contribute to higher quality

corporate innovation. van de Wal et al. (2020) use a sample of 109 CEOs from 87 U.S.-based pharmaceutical firms over the period 2001–2013 as a sample to investigate the impact of CEO research orientation on firm innovation outcomes. This study shows that research-oriented CEOs increase their firms' innovation outcomes.

R&D background of top executives are considered important for corporate innovation because it represents top executives' superior ability to assess, select, and conduct innovative investment projects based on their R&D experience (Islam and Zein, 2020). It also indicates a company's critical organisational conditions in which innovation capabilities reside (Talke et al., 2010; Amyx, 2019; van de Wal et al. 2020). However, the relationship between R&D background of top executives and corporate innovation is not yet obvious. Despite their R&D experience, top executives may be incapable of commercialising or marketing their firms' technologies (Islam and Zein, 2020), or lack other functional or operational capabilities. Thus, whether and how a R&D background enhances a top executive's ability to successfully spark firm-wide innovation remain open empirical questions. This paper aims to answer these questions using a sample of high-technology firms in China.

2.2 Hypothesis development

2.2.1 Top executives' R&D background and corporate innovation outcomes

Existing literature shows that individual characteristics can affect both creativity (e.g., Oldham and Cummings, 1996) and receptivity to innovative ideas (e.g., Kimberly and Evanisko, 1981). Furthermore, according to the theory of upper echelons, the

cognitive resources, experience, and values of top executives have a particularly significant influence upon a firm's strategic choices (Hambrick and Mason, 1984). We posit that R&D background as an individual characteristic of top executives can be associated with innovation outcomes for the following reasons.

First, from the perspective of managerial attitudes and beliefs, R&D background, particularly long-term R&D experience, enable top executives to develop their attitudes and beliefs on the importance of innovation. Such beliefs are important as they help give higher priority to innovation and create an innovative organisational culture. Echoing with the above idea, Mr Umesh Gupta, Additional General Manager at Bharat Heavy Electricals LTD, pointed out at a colloquium on 'Creativity, Entrepreneurship, and Organisations of the Future' at Harvard Business School that 'Innovation in any place, including commercial organisations, is directly proportional to the attitude of senior management.'⁶

Second, from the perspective of decision-making processes, cognitive resources and expertise assist problem identification, formulation, exploration, and problem solving (e.g. Bantel and Jackson, 1989; Finkelstein, 1992). Finkelstein (1992) further point out that product R&D and process R&D are two of the functional areas that represent critical expertise. Therefore, having a R&D background equips top executives with necessary cognitive resources and expertise on innovation. A broader cognitive base gives top executives an advantage by enabling them to effectively identify innovation problems, make strategic innovation choices, solve the problems, and garner first mover advantages (Hayton, 2005).

Third, from the perspective of managing innovation activities, top executives with R&D background create the organisational conditions and culture to foster innovation such as changing the compensation schemes of R&D executives and increasing their managerial discretion (Lerner and Wulf, 2007), attracting talents through labour market sorting (Van den Steen, 2005), prompting tolerance for failure (Tian and Wang, 2014), and allocating more resources to R&D (Amyx, 2019). This, in turn, increases innovation outcomes.

Fourth, as innovation activities are usually full of complexity and uncertainty and consume a large amount of resources, top executives' R&D background enable them to accumulate innovation-related reputational, social, and relational capitals, which play significant roles in corporate innovation activities. For example, Hayton (2005) point out that top executives' positive reputation and broad social and professional networks provide strong support for a firm's innovation activities by reducing the effect of resource scarcity as those capital reduce the risks that potential stakeholders perceive in establishing a relationship with the firm.

Last but not least, because innovation serves as an indication of managerial ability, successful innovation is rewarded by the market for managers (Aghion et al., 2013; Galasso and Simcoe, 2011). Galasso and Simcoe (2011) further find that CEOs are more likely to pursue innovation in more competitive industries. Therefore, from the perspective of career concern, we posit that top executives with R&D background have incentives to actively pursue innovation, and that this effect is particularly profound in high-technology industries.

The above arguments indicate that the R&D background characteristic of top executives are a valuable organisational resource. Therefore, it is expected that R&D background of top executives has a significant influence on corporate innovation outcomes. Hence, we posit that:

Hypothesis 1: R&D background of top executives has a positive effect on innovation outcomes.

2.2.2 Mediating effect of R&D expenditure

First of all, it is argued that top executives with R&D background are motivated to allocate funds to the R&D function. That is because successful R&D projects, particularly key R&D projects of high-technology firms, indicate high managerial ability of top executives (Aghion et al., 2013; Galasso and Simcoe, 2011). Accordingly, devoting funding to R&D can benefit their self-interests because it can be used to support compensation, reputation, career development, and so on. (Dalziel and Gentry, 2011).

From the perspective of managerial attitudes and beliefs, top executives with R&D background tend to value the contribution of R&D investment as a precursor of innovation, and in turn are willing to invest on R&D activities. For example, Hayes and Abernathy (1980) posit that top managers with experience primarily in R&D are more likely to focus on and comprehend the consequences of the proposed investments in product innovation and process technology.

From the perspective of functional expertise, top executives with R&D background

can be said to be experts in product and/or process R&D (Finkelstein, 1992). Such knowledge and expertise allow them to provide advice or make decisions on R&D projects. Therefore, top executives with R&D background will be more capable than other top executives of making R&D investment decisions.

Top executives' R&D background also sends out powerful messages to finance providers about their understanding, expertise and emphasis on R&D projects which are characterised with high degree of uncertainty (Useem, 1979; Hall and Lerner, 2010). These messages are important because they help reduce the information asymmetry between funds users and providers, which makes it relatively easy for firms to obtain external finance for their R&D projects. The role of top executives' R&D background is expected to be particularly important in high-technology firms because of their typically sophisticated and untransparent natures in business as compared with other firms.

Empirical findings from the TMT literature consistently support the view that technical experience has a positive influence on R&D expenditure (e.g. Schoenecker et al., 1995; Tyler and Steensma, 1998; Daellenbach et al., 1999; Barker and Mueller, 2002; Dalziel and Gentry, 2011). Collectively, these arguments and evidence suggest that top executives' R&D background will enhance R&D investments. We therefore propose the following hypothesis:

Hypothesis 2a: R&D background of top executives has a positive effect on R&D expenditure.

R&D has been the determinant of innovation that has received the most attention from researchers because R&D investment is one of the most important mechanisms in determining innovation (Baldwin and Hanel, 2003; Becheikh et al., 2006). R&D investments are important to innovation because they are vital to create the new knowledge required to develop innovations. This is particularly true for innovations of a high degree of novelty, which consumes heaps of resources and requires high level of R&D investments (Romijn and Albaladejo, 2002; Caloghirou et al., 2004; Amara et al., 2008).

Given the vital role of R&D investments in innovation, one can expect that R&D background of top executives help them effectively set up R&D investment strategies and allocate resources for R&D investments, which, in turn, strengthen innovation outcomes. Specifically, on the one hand, top executives' R&D background enable them to effectively organise R&D activities by allocating the right resources to the right R&D projects at the right time. This effectiveness in the organisation of R&D activities ensures high-quality transfer from R&D investments as innovation inputs to innovation outputs. This is particularly important for high-technology firms because of the high complicity of R&D projects in nature. On the other hand, top executives' knowledge and experience in R&D ensure that they can quickly respond to any opportunities or changes emerged in the development of technology, which is particularly important for high-technology industries because intense competition is apparent and time is of essence in those industries. As speed is one of the important characteristics of innovation preformance, transferring R&D investments to innovation outputs in an

efficient manner will become one of the firm's competitive advantages in innovation.

These arguments suggest that R&D investments intervene in the relationship between top executives' R&D background and innovation outcomes by playing a mediating role. Therefore, we posit that:

Hypothesis 2b: R&D expenditure plays a mediating role in the relationship between top executives' R&D background and innovation outcome.

2.2.3 Moderating effect of risk-taking

Existing literature on innovation has identified a couple of contingency factors that can influence the relationship between R&D and innovation (Damanpour,1996). Among the possible factors, top executives' attitude towards risk play an important role in their R&D investment decision making because R&D investments are featured with long payback period and high risk (Tan, 2001).

Top executives with R&D background present path dependence on R&D investments when dealing with risks. More specifically, their R&D experience would enable them to believe the importance of R&D investments in dealing with risks on the one hand. On the other hand, based on the upper echelons theory and resources-based view, top executives' human, social and relational capitals would make them capable of doing so. This is particularly important when firms are facing financial constraints because top executives with R&D background may prioritise R&D investments in the event of financial constraints. Also, according to prospect theory, decision makers are more sensitive to losses compared with gains, but they generally present risk seeking

preference in the domain of losses because of the certainty effect (Kahneman and Tversky, 2013). Wiseman and Gomez-Mejia (1998) further argue that when the forecasted performance is unsatisfactory, executives may anticipate losses to their personal wealth. Because their wealth is effectively already lost, executives tend to take greater strategic risks on behalf of the firm (there is nothing more to lose). Therefore, despite the increase in risks, or even in the event of distress, top executives with R&D background may still actively engage in R&D activities and increase R&D investments.

From the perspective of managerial reputation and career concern, when a firm faces risks, it will attract attention, monitoring, or even criticisms from shareholders and other stakeholders. In this case, top executives with R&D background are able to capitalise their expertise and experience in selecting R&D projects and managing R&D activities to engage in R&D initiatives, which is a means of boosting stakeholder confidence in the firm and improving their personal reputation. This is particularly true for high-technology firms. Top executives with R&D background as insiders can also use their information advantage to increase their negotiation power with shareholders and find excuses for declining performance, which help them reduce the possibility of dismissal and career concerns.

To sum up, these arguments suggest that top executives with R&D background tend to increase R&D expenditure when the level of corporate risk-taking is high. Hence, we propose the following hypothesis:

Hypothesis 3a: Corporate risk-taking positively moderates the relationship between top executives' R&D background and R&D expenditure, i.e., top executives

with R&D background tend to increase R&D expenditure when the level of corporate risk-taking is high.

On the one hand, corporate risk-taking represents executives' willingness to take risks in the pursuit of profitable opportunities (Faccio et al., 2011). More specifically, top executives with R&D background tend to have a strong belief on the importance of innovation. Because of this belief, top executives would support innovation activities through maintaining or even increasing R&D investments in the event of volatility in performance and high uncertainty (Yun, 2016). Also because of this belief, top executives with R&D background tend to promote an organisational culture that encourages innovation and tolerates failure, which benefits innovation efficiency and outcome (Tian and Wang, 2014; Sunder et al., 2017).

On the other hand, R&D background would enable top executives to know well about innovation practices, improve innovation strategies, facilitate cooperation among various departments and teams to support the conduct of R&D projects, and integrate various technologies and knowledge resources (Galasso and Simcoe, 2011). More importantly, top executives with R&D background are deemed to provide continuous funds especially at the critical stages to bypass the difficult periods, which greatly helps improve innovation outcomes. The above arguments are particularly true for high-technology firms because of severe competition they face.

Collectively, these arguments indicate that corporate risk-taking is expected to intervene in the relationship between top executives' R&D background, R&D

investments, and innovation outcome by exerting a moderating effect. Thus, we posit that:

Hypothesis 3b: Corporate risk-taking positively moderates the mediating role of R&D expenditure in the relationship between top executives' R&D background and innovation outcomes, i.e., the effect of top executives' R&D background on innovation outcomes through R&D expenditure is more profound when risk-taking is high than that when risk-taking is low.

To illustrate our hypotheses, we develop a conceptual framework (see **Figure 1**).

[insert Figure 1 about here]

3. Research design

3.1 Data and sample

Our sample consists of A-share companies in the high-technology industries listed on the Main Board and Growth Enterprise Market over the period 2012-2017. High-technology industries are determined according to the High-tech Classification of Manufacturing Industries (2017) and High-tech Classification of Service Industries (2018) issued by the National Bureau of Statistics of China. We exclude firms marked with ST and *ST, and observations with a ratio of debt-to-total assets being bigger than 1.⁷ All continuous variables are winsorised at the 1st and 99th percentiles. We also eliminate firms that never disclose R&D and patent information during our sample period. Applying the abovementioned filters yields our final unbalanced panel dataset consisting of 798 firms and 3,535 firm-year observations. Data on characteristics of corporate top executives are obtained from Wind Information Co., Ltd (henceforth

WIND) and the China Stock Market & Accounting Research (*CSMAR*) Database, which are leading financial data and solutions providers in China.⁸ Annual reports and companies' websites are used to source some missing information from the abovementioned databases. Data on innovation outcomes are from *CSMAR*. Data on innovation outcomes missed in *CSMAR* for some companies are further obtained from other sources, including Patent Database Service Platform of China Intellectual Property Right Net (for patents registered in China), European Patent Office (EPO, for patents registered in Europe), and United States Patent and Trademark Office (USPTO, for patents registered in the US), where possible⁹.

3.2 Variables

The dependent variable is measured by both the quantity and quality of innovation outcomes. Following Dosi et al. (2016), Hall and Harhoff (2012), and Tan et al. (2014), among others, we use the number of patent applications to proxy for the quantity of innovation outcomes. One reason of using the number of patent applications rather than the number of granted patents is that patent grants are prone to bureaucratism (Tan et al., 2014). Following Fabry et al. (2006) and Hao et al. (2018) and given the availability of the patent data in China, we choose to use the number of International Patent Classification (IPC) that a patent covers to proxy for the quality of innovation outcomes.¹⁰ Because a high number of IPC of a patent indicates that the innovation output tends to be more fundamental and generalisable, the higher the number of IPC, the higher the quality of innovation outcomes.

Following Daellenbach et al. (1999), among others, the independent variable in this study, i.e., R&D background (*R&D_background*), is constructed based on the background of corporate top executives. Specifically, we manually check the resume of the top executives of a firm and assign to the variable the value 2 if both the chairman and CEO of the firm have experience in R&D from firms, universities, or R&D-related institutes, 1 if either the chairman or CEO of the firm has the abovementioned experience, and 0 if none of the chairman and CEO has the abovementioned experience. For example, Mr Daokui Qu, who is the current CEO of Siasun Robot & Automation Co., Ltd. (stock code: 300024.SZ), first worked on robots in the State Key Laboratory of Robotics after he graduated from Shenyang Institute of Automation Chinese Academy of Sciences in 1986.

The mediator variable in this study is R&D expenditure (*R&D*). Following existing literature, *R&D* is measured as the natural logarithm of a firm's R&D expenditure. As existing literature also uses R&D intensity, calculated as R&D expenditure divided by sales revenue, to proxy for R&D expenditure, we use R&D intensity as an alternative measure for R&D expenditure in a robustness test.

The moderator variable in this study is corporate risk-taking (*Risk*). Following Boubakri et al. (2013) and Faccio et al. (2014), *Risk* is measured as the five-year standard deviation of a firm's return on assets (ROA). The underlying idea is that corporate high-risk decision making is full of uncertainty, which causes volatility in financial performance.

Following existing literature, this paper includes a set of control variables, such as

duality (*Dual*), state ownership (*State*), board size (*Board*), Leverage (*Lev*), and cash holdings (*Cash*). Detailed definitions of variables can be seen in **Table 1**.

[insert Table 1 about here]

3.3 Model specifications

To test the effect of the R&D background of top executives on innovation outcomes, we specify the following panel data regression model:

$$Innovation_outcomes_{i,t+1} = \alpha_0 + \alpha_1 R\&D_background_{i,t} + Controls_{i,t} + \varepsilon_{i,t} \quad (1)$$

where *Innovation_outcomes* is measured by *PATNUM* and *PATIPC* and R&D background of top executives is represented by *R&D_background*. Given the potential endogeneity issue and the possibly lagged effect of *R&D_background* on *Innovation_outcomes*, the main independent variable takes the lagged value.

To test the mediating effect of R&D expenditure in the relationship between R&D background and innovation outcomes, we specify the following panel data regression model:

$$R\&D_{i,t+1} = \alpha_0 + \alpha_1 R\&D_background_{i,t} + Controls_{i,t} + \varepsilon_{i,t} \quad (2)$$

$$\begin{aligned} Innovation_outcomes_{i,t+1} \\ = \alpha_0 + \alpha_1 R\&D_background_{i,t} + \alpha_2 R\&D_{i,t} + Controls_{i,t} + \varepsilon_{i,t} \quad (3) \end{aligned}$$

where *R&D* represents R&D expenditure. Following Baron and Kenny (1986) and Wen and Ye (2014), if the following criteria are satisfied

- the coefficient of independent variable, i.e., *R&D_background*, in Model (1) is statistically significant,

- the coefficient of *R&D_background* in Model (2) is statistically significant,
and
- the coefficient of *R&D* in Model (3) is statistically significant

then the mediating effect of R&D expenditure in the relationship between R&D background and innovation outcomes is identified.

To test the moderating effect of risk-taking on the relationship between top executives' R&D background and R&D expenditure and further on the mediating role of R&D expenditure in the relationship between R&D background and innovation outcomes, we specify the following panel data regression model:

$$R\&D_{i,t+1} = \alpha_0 + \alpha_1 R\&D_background_{i,t} + \alpha_2 Risk_{i,t} + \alpha_3 R\&D_background_{i,t} \times Risk_{i,t} + Controls_{i,t} + \varepsilon_{i,t} \quad (4)$$

$$\begin{aligned} Innovation_outcomes_{i,t+1} &= \alpha_0 + \alpha_1 R\&D_background_{i,t} + \alpha_2 Risk_{i,t} \\ &+ \alpha_3 R\&D_background_{i,t} \times Risk_{i,t} + Controls_{i,t} + \varepsilon_{i,t} \end{aligned} \quad (5)$$

$$\begin{aligned} Innovation_outcomes_{i,t+1} &= \alpha_0 + \alpha_1 R\&D_background_{i,t} + \alpha_2 Risk_{i,t} \\ &+ \alpha_3 R\&D_background_{i,t} \times Risk_{i,t} + \alpha_4 R\&D_{i,t} + Controls_{i,t} \\ &+ \varepsilon_{i,t} \end{aligned} \quad (6)$$

where *Risk* represents corporate risk-taking. Following Wen et al. (2006), Wen and Ye (2014) and Ovuakporie et al. (2021) among others, if the coefficient of the interaction term between *R&D_background* and *Risk* in Model (6) is statistically significant, then the moderating effect of risk-taking on the relationship between top executives' R&D background and innovation outcomes is identified. If

- the coefficient of the interaction term between *R&D_background* and *Risk* in Model (5) is statistically significant, and
- the coefficient of *R&D* in Model (6) is statistically significant

then a moderated mediation effect is identified.

Note that the above models have passed the heteroscedasticity test. We further conduct the PSM test as part of the robustness tests to address the potential endogeneity concern. Firm and year fixed effects are also included.

4. Results

4.1 Descriptive statistics

Table 2 presents the descriptive statistics of the main variables. The standard deviation of *PATNUM* is 400.404, indicating a high variation of the number of patent applications among the sample firms. This is not surprising because the number of patent applications of some firms, such as BOE Technology Group Co., Ltd. and TCL Technology Group Co., Ltd., can reach around 7,000 per year, whereas that of some firms is minimal. A similar pattern is found in *PATIPC*. *R&D_background* is 0.86 on average, indicating that top executives, including chairman and CEO, of a large proportion of our sample firms have R&D background.¹¹ This statistic highlights the importance of investigating the impact of R&D background on innovation outcomes in China. *R&D*, on average, is 18.094. This indicates that the average R&D expenditure of our sample firms is 72,131,399.01 RMB. *Risk*, which is measured as the five-year standard deviation of a firm's ROA, is 0.087 on average.

[insert Table 2 about here]

Table 3 presents the correlation coefficient between the key variables, which shows positive correlations between R&D background and innovation outcomes. This result provides preliminary evidence consistent with our hypothesis 1. We also conduct the correlation analysis between independent variable and control variables, which shows that the correlation coefficients and VIF are relatively small. This indicates that the multicollinearity problem is not a big concern.

[insert Table 3 about here]

4.2 Regression results

The fixed-effect (FE) panel regression is applied to Model (1) based on Hausman test. As shown in Columns (1) and (2) of **Table 4**, top executives' R&D background has a significantly positive effect on both the quantity (*PATNUM*) and quality (*PATIPC*) of innovation outcomes. This result suggests that R&D background of top executives in a firm helps the firm increase its innovation outcomes. Therefore, Hypothesis 1 is supported.

Column (3) of **Table 4** reports a significantly positive effect of top executives' R&D background on R&D expenditure, indicating that R&D background of top executives in a firm helps the firm increase its R&D expenditure. Hypothesis 2a is thus supported. Note that it is not surprising for high-technology firms to maintain their core competencies through consistently high R&D expenditure. However, by only selecting high-technology firms as a sample, our results show that top executives' R&D

background still exerts a positive effect on R&D expenditure among high-technology firms.

Model (3) incorporates both top executives' R&D background and R&D expenditure to examine the mediating effect of R&D expenditure in the relationship between R&D background and innovation outcomes. Column (4) of **Table 4** shows that the estimated coefficient of *R&D_background* is statistically significant, indicating that R&D expenditure plays a partial mediation role in the relationship between R&D background and the quantity of innovation outcomes. Column (5) of **Table 4**, however, presents a statistically insignificant estimated coefficient of *R&D_background*, indicating that R&D expenditure plays a full mediation role in the relationship between R&D background and the quality of innovation outcomes. The results support Hypothesis 2b, which suggests that R&D expenditure is one of the channels through which top executives' R&D background affects innovation outcomes.

Among control variables, duality (*Dual*) is positively related to innovation outcomes. This result may indicate that duality increases the concentration of power, which ensures effective implementation of strategies and innovation outcomes. Board size (*Board*) is consistently and negatively associated with R&D expenditure and both innovation outcomes measures, which may indicate a detrimental effect of a large board size on innovation activities due to the increasing likelihood of dispute with the size of the board. State ownership (*State*) is consistently and negatively correlated with innovation outcomes, suggesting that compared with state-owned enterprises (SOEs), non-SOEs are more likely to achieve innovation outcomes. This result is consistent with

Chesbrough et al. (2021) and Clarke (2017) showing that non-SOEs have been faster to adopt the latest technologies, in comparison to the SOEs.

[insert Table 4 about here]

Table 5 reports the results on the moderating effect of risk-taking on the relationship between top executives' R&D background and R&D expenditure and further on the mediating role of R&D expenditure in the relationship between R&D background and innovation outcomes. Column (1) of **Table 5** shows that a firm's risk-taking can have a diminishing effect on its R&D expenditure, but firms that have top executives with R&D background have promised higher R&D expenditure than those that do not have R&D-background top executives. This result suggests that top executives with R&D background exhibit risk preference attitude and tend to increase R&D expenditure to proactively deal with risk. Therefore, Hypothesis 3a is supported.

A similar result is shown in Columns (2)-(3) as that in Column (1), i.e., although a firm's risk-taking can have a diminishing effect on its innovation outcomes, firms that have top executives with R&D background have achieved better innovation outcomes than those that do not have R&D background top executives. The above result can be seen from the positive coefficient of the interaction term between *R&D_background* and *Risk* in Columns (2)-(3). Furthermore, the estimated coefficient of R&D expenditure (*R&D*) in Column (4) and (5) is positive. According to Wen and Ye (2014) and Wen et al. (2016), the above results all together indicate that the effect of top executives' R&D background on innovation outcomes through R&D expenditure is

more profound when risk-taking is high than that when risk-taking is low. In other words, the role of top executives' R&D background of a firm is further important when the firm's risk-taking is high in that R&D background of top executives help the firm achieve further innovation outcomes through increasing R&D expenditure. Therefore, a positive moderation effect of corporate risk-taking on the mediating role of R&D expenditure in the relationship between top executives' R&D background and innovation outcomes, i.e., a moderated mediating effect, is observed. Hypothesis 3b gets supported.

[insert Table 5 about here]

4.3 Robustness tests

4.3.1 Endogeneity caused by unobservable variables

The positive correlation between top executives' R&D background and innovation outcomes observed in our baseline results could be caused by unobservable variables that may also explain innovation outcomes. To address such as concern, we attempt to analyse variations among firms led by top executives with R&D background only. The underlying rationale is that if top executives' R&D background does drive the above positive correlation, then this effect should be stronger for top executives with longer R&D experience. Hence, we use the duration of the R&D-related experience of top executives (*Duration*) as an alternative measure. *Duration* is measured as the natural logarithm of a top executive' duration of R&D-related experience from the first year of their first R&D-related experience to the sample year. Columns (1) and (2) of **Table 6**

present the results, which show that the coefficients of *Duration* are positive and statistically significant at the 1 per cent level. This result indicates that the longer the R&D experience of the top executive (CEO *or* chairman) is, the better the innovation outcomes. We further explore whether the above impact is profound if both the CEO *and* chairman of a firm have R&D-related experience. In such cases, *Duration* of the firm is calculated as the average of the duration of CEO and chairman. Columns (3) and (4) of **Table 6** show that the coefficients of *Duration* are not only positive and statistically significant but also bigger in magnitude than those in column (1) and (2). This result suggests that both CEO and chairman having R&D-related experience does strengthen the impact of such an experience on innovation outcomes.

[insert Table 6 about here]

4.3.2 Endogeneity caused by reverse causality and/or self-selection

Given that the relationship between top executives' R&D background and innovation outcomes may be endogenous in that innovation outcomes may cause firms to select top executives with R&D background (Chaganti and Sambharya, 1987; Thomas et al., 1991; Datta and Guthrie, 1994), we employ the PSM method to tackle the potential endogeneity issue. The results presented in **Table 7** show that regardless of whichever matching tactic is used top executives' R&D background significantly improves corporate R&D spending and innovation outcomes. Hence, our baseline results in **Table 4** and **5** are qualitatively unchanged.

[insert Table 7 about here]

We also employ the two-stage least squares (2SLS) approach to further address the potential endogeneity concern. More specifically, we use the industry mean of R&D intensity in the previous year as an instrumental variable to estimate the 2SLS model. F value in the first stage of the regression is above 10, indicating no evidence that our instrumental variable is weak. The second stage of the regression is presented in **Table 8**, which shows that our baseline results hold.

[insert Table 8 about here]

This study may be subject to endogeneity concern caused by selection bias in that our sample may have not been selected randomly (Antonakis et al. 2010). To address such a potential concern, we employ the Heckman two-stage model. To illustrate, we introduce the industry mean of R&D expenditure in the previous year at the first stage of the regression. The inverse Mills ratio (*Imr*) generated from the first stage is not significantly associated with innovation outputs and R&D expenditure in the second stage (see details in **Table 9**). The overall results show that our baseline results remain constant after addressing endogeneity.

[insert Table 9 about here]

4.3.3 Other robustness tests¹²

We also do some other robustness tests to further ensure the robustness of our results. Specifically, we use an alternative measure of R&D expenditure, i.e., the ratio of R&D expenditure to sales revenue. We also use the natural logarithm of the number of patent applications for inventions only as an alternative measure of the quantity of

innovation outcomes. The results of these robustness tests show that our baseline results largely remain constant.

5. Conclusions and discussions

Given the important but yet underexplored role of R&D background of top executives played in corporate R&D and innovation practices, this study uses a sample of listed firms in the high-technology industries in China over the period of 2012-2017 to investigate the impact of top executives' R&D background on corporate innovation outcomes and further examine the mediating effect of R&D spending and moderating effect of risk-taking on the above relationship. We find that R&D background of top executives is positively associated with innovation outcomes. We also find that top executives' R&D background affects innovation outcomes via R&D expenditure which plays a mediating role in the R&D background-innovation relationship. Moreover, we find that the effect of top executives' R&D background on innovation outcomes through R&D expenditure is further profound when risk-taking is high, i.e., the moderating effect of corporate risk-taking.

Our findings support the positive role played by top executives' R&D background in enhancing corporate innovation outcomes. This may help explain the thrive of the high-technology industries in China and the increasingly strong position of China as an emerging global innovation leader. Moreover, our study reveals that the positive contribution abovementioned is achieved through the willingness and capacity of top executives with R&D background to ensure R&D spending especially when corporate

risk-taking is high. Findings of our study have important implications for firms that aim to enhance their innovation outcomes. First, high-technology firms need to optimise their structure of top executives to allow for the increase of the voice and power of top executives with R&D background when setting up and implementing their innovation strategies. Second, firms need to develop the organisational culture to promote tolerance for failure and proactively respond to risks. Our findings also have implications for countries, especially developing countries, regarding their research policymaking and R&D management (Hwang, Suh, & Kim, 2017). To illustrate, on a macro level, the government in developing countries may make policies to create an environment where innovation activities are encouraged and supported. On a micro level, firms may introduce incentives to attract executives with R&D background and tolerate failure.

Although we examine the consequences of top executives' R&D background, we do not study the antecedents of top executives' R&D background, i.e., why and how technocrats become top management, which calls for future research. The extremely small size of the sample where non-R&D-background top executives become R&D-background top executives during our sample period does not allow us to conduct a difference-in-difference (DID) test as an alternative way to address the potential endogeneity concern. Future research may consider doing such a test when sufficient data are available. Moreover, although our primary focus is R&D investments as the mediating factor and corporate risk-taking as the moderating factor, which are arguably the most important factors that affect innovation particularly for high-technology firms,

we do recognise the possibility of other channels and moderators, such as emotional support, organisational culture, top executive networks, and so on. Future research may continue to explore the impact of these possible factors on innovation when data are available.

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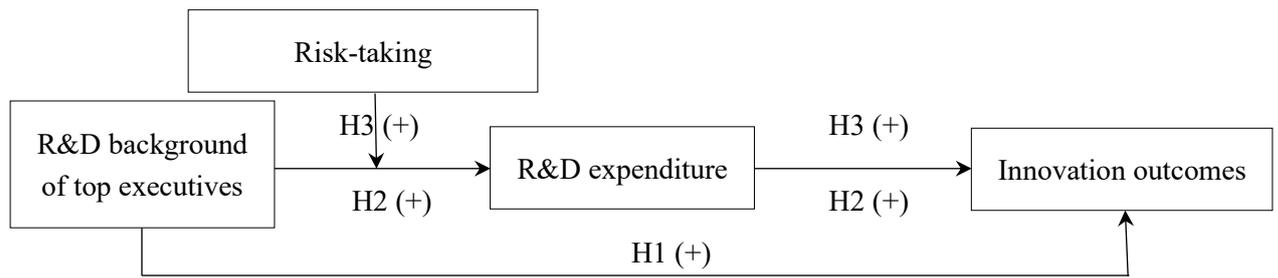


Figure 1. Conceptual framework

Table 1. Definitions of main variables

Categories	Variable name	Symbol	Definitions
Dependent variables	Quantity of innovation outcomes	<i>PATNUM</i>	Natural logarithm of total number of patent applications for inventions, utility models and designs
	Quality of innovation outcomes	<i>PATIPC</i>	Number of International Patent Classification that a patent covers
Independent variable	R&D background of top executives	<i>R&D_background</i>	Experience of the chairman and/or CEO of a firm in R&D from firms, universities, or R&D-related institutes. It takes the value 2 if both the chairman and CEO of the firm have experience in R&D from firms, universities, or R&D-related institutes, 1 if either the chairman or CEO of the firm has the abovementioned experience, and 0 if none of the chairman and CEO has the abovementioned experience
Mediating variable	R&D expenditure	<i>R&D</i>	Natural logarithm of a firm's R&D expenditure
Moderating variable	Corporate risk-taking	<i>Risk</i>	Five-year standard deviation of a firm's ROA
Control variables	Duality	<i>Dual</i>	A dummy variable that equals 1 if CEO is also the chair of the board and 0 otherwise
	State ownership	<i>State</i>	A dummy variable that equals 1 if the firm is owned by state and 0 otherwise
	Board size	<i>Board</i>	Number of directors
	Leverage	<i>Lev</i>	Ratio of total liabilities to total assets
	Cash holding	<i>Cash</i>	Natural logarithm of a firm's cash holding

Table 2. Descriptive statistics of variables

	Obs.	Mean	Median	Min	Max	Std. Dev.
<i>PATNUM</i>	3,535	88.542	24	0	7803	400.404
<i>PATIPC</i>	3,535	40.787	20	0	444	63.352
<i>R&D_background</i>	3,535	0.86	1	0	2	0.894
<i>R&D</i>	3,535	18.094	17.947	9.169	25.025	1.245
<i>Risk</i>	3,535	0.087	0.032	0.007	18.441	1.153
<i>Dual</i>	3,535	0.349	0	0	1	0.477
<i>State</i>	3,535	0.247	0	0	1	0.431
<i>Board</i>	3,535	8.444	9	4	17	1.677
<i>Lev</i>	3,535	0.307	0.315	0	1.352	0.19
<i>Cash</i>	3,535	20.070	20.013	15.733	24.786	1.112

Note: All variables are defined in **Table 1**.

Table 3. Correlation analysis

	<i>R&D_ background</i>	<i>Risk</i>	<i>PATNUM</i>	<i>PATIPC</i>	<i>R&D</i>	<i>State</i>	<i>Dual</i>	<i>Board</i>	<i>Lev</i>
<i>Risk</i>	-0.028*								
<i>PATNUM</i>	0.062***	-0.020							
<i>PATIPC</i>	0.501***	-0.034**	0.639***						
<i>R&D</i>	0.027	-0.082***	0.374***	0.570***					
<i>State</i>	-0.022	-0.089***	0.121***	0.209***	0.213***				
<i>Dual</i>	0.043	0.011	-0.063***	-0.102***	-0.119***	-0.292***			
<i>Board</i>	-0.048***	-0.073***	0.118***	0.125***	0.169***	0.292***	-0.221***		
<i>Lev</i>	-0.110***	-0.031*	0.175***	0.252***	0.270***	0.262***	-0.103***	0.129***	
<i>Cash</i>	-0.012	-0.034**	0.327***	0.462***	0.634***	0.269***	-0.127***	0.237***	0.203***

Notes: *, **, and *** indicate statistical significance at 10 per cent, 5 per cent, and 1 per cent levels, respectively. All variables are defined in **Table 1**.

Table 4. Effect of top executives' R&D background on innovation outcomes and the mediating effect of R&D expenditure

	Model (1)		Model (2)	Model (3)	
	<i>PATNUM</i>	<i>PATIPC</i>	<i>R&D</i>	<i>PATNUM</i>	<i>PATIPC</i>
	(1)	(2)	(3)	(4)	(5)
<i>R&D_background</i>	0.239*** (4.23)	0.180*** (3.07)	0.210*** (5.55)	0.143*** (2.65)	0.079 (1.42)
<i>R&D</i>				0.457*** (16.64)	0.478*** (16.76)
<i>Dual</i>	0.157*** (2.81)	0.160*** (2.76)	0.072* (1.94)	0.124** (2.33)	0.125** (2.28)
<i>Board</i>	-0.06 (-0.38)	-0.094 (-0.58)	-0.151 (-1.43)	0.01 (0.06)	-0.022 (-0.14)
<i>State</i>	-0.013*** (-4.42)	-0.018*** (-5.63)	-0.020*** (-10.35)	-0.004 (-1.29)	-0.007** (-2.53)
<i>Cash</i>	0.338*** (13.9)	0.335*** (13.26)	0.327*** (20.15)	0.188*** (7.57)	0.178*** (6.92)
<i>Lev</i>	1.004*** (6.32)	1.025*** (6.22)	1.192*** (11.24)	0.458*** (2.96)	0.455*** (2.84)
<i>Firm FE</i>	Yes	Yes	Yes	Yes	Yes
<i>Year FE</i>	Yes	Yes	Yes	Yes	Yes
<i>Cons</i>	-3.689*** (-6.09)	-3.534*** (-5.62)	11.797*** (29.16)	-9.091*** (-13.73)	-9.172*** (-13.36)
<i>Adj-R²</i>	0.172	0.146	0.247	0.316	0.328
<i>Obs.</i>	3,535	3,535	3,535	3,535	3,535

Notes: t-value is included in the parentheses. *, **, and *** indicate statistical significance at 10 per cent, 5 per cent,

and 1 per cent levels, respectively. Firm and year fixed effects (FE) estimators are used in the panel regression. All

variables are defined in **Table 1**.

Table 5. Moderated mediating effect of risk-taking

	Model (4)	Model (5)		Model (6)	
	<i>R&D</i>	<i>PATNUM</i>	<i>PATIPC</i>	<i>PATNUM</i>	<i>PATIPC</i>
	(1)	(2)	(3)	(4)	(5)
<i>R&D_background</i>	0.187*** (4.74)	0.129** (2.12)	0.117* (1.89)	0.078 (1.37)	0.062* (1.71)
<i>R&D_background</i> × <i>Risk</i>	0.683** (2.44)	2.406*** (4.74)	1.448*** (3.29)	1.441*** (3.56)	0.881** (2.43)
<i>Risk</i>	-3.554*** (-8.00)	-2.556*** (-4.81)	-2.483*** (-3.56)	-1.431** (-2.21)	-0.831** (-2.46)
<i>R&D</i>				0.453*** (16.28)	0.497*** (22.04)
<i>Dual</i>	0.073** (1.99)	0.156*** (2.79)	0.160*** (2.77)	0.124** (2.33)	0.017 (0.38)
<i>Board</i>	-0.111 (-1.07)	-0.052 (-0.32)	-0.081 (-0.49)	0.008 (-0.05)	-0.063 (-0.53)
<i>State</i>	-0.017*** (-9.01)	-0.012*** (-4.27)	-0.016*** (-5.25)	-0.004 (-1.31)	-0.003* (-1.69)
<i>Cash</i>	0.325*** (20.29)	0.332*** (13.73)	0.333*** (13.2)	0.188*** (7.57)	0.148*** (6.73)
<i>Lev</i>	1.066*** (10.09)	1.004*** (6.33)	0.974*** (5.87)	0.458*** (2.95)	0.463*** (3.74)
<i>Firm FE</i>	Yes	Yes	Yes	Yes	Yes
<i>Year FE</i>	Yes	Yes	Yes	Yes	Yes
<i>Cons</i>	11.864*** (29.68)	-3.487*** (-5.77)	-3.424*** (-5.45)	-8.932*** (-13.44)	-8.960*** (-18.65)
<i>Adj-R²</i>	0.302	0.118	0.153	0.314	0.344
<i>Obs.</i>	3,535	3,535	3,535	3,535	3,535

Notes: t-value is included in the parentheses. *, **, and *** indicate statistical significance at 10 per cent, 5 per cent,

and 1 per cent levels, respectively. Firm and year fixed effects (FE) estimators are used in the panel regression. All

variables are defined in **Table 1**.

Table 6. Alternative measure of R&D background of top executives

	CEO <i>or</i> chairman		CEO <i>and</i> chairman	
	<i>PATNUM</i>	<i>PATIPC</i>	<i>PATNUM</i>	<i>PATIPC</i>
	(1)	(2)	(3)	(4)
<i>Duration</i>	0.066** (2.57)	0.084*** (3.17)	0.100*** (5.38)	0.107*** (5.56)
<i>Dual</i>	0.364** (2.43)	0.567*** (3.67)	0.111 (1.07)	0.057 (0.54)
<i>Board</i>	0.076 (0.28)	0.158 (0.56)	0.125 (0.39)	0.111 (0.33)
<i>State</i>	-0.012* (-1.81)	-0.012* (-1.76)	0.005 (0.60)	-0.010 (-1.15)
<i>Cash</i>	0.138*** (2.71)	0.130** (2.48)	0.289*** (5.44)	0.241*** (4.35)
<i>Lev</i>	0.412 (1.24)	0.538 (1.57)	0.889** (2.44)	0.772** (2.04)
<i>Firm FE</i>	Yes	Yes	Yes	Yes
<i>Year FE</i>	Yes	Yes	Yes	Yes
<i>Cons</i>	-0.128 (-0.10)	-0.604 (-0.47)	-5.577*** (-4.15)	-4.475*** (-3.20)
<i>Adj-R²</i>	0.166	0.165	0.271	0.251
<i>Obs.</i>	846	846	1,008	1,008

Notes: t-value is included in the parentheses. *, **, and *** indicate statistical significance at 10 per cent, 5 per cent,

and 1 per cent levels, respectively. Firm and year fixed effects (FE) estimators are used in the panel regression. All

variables are defined in **Table 1**.

Table 7 Result of the PSM Test

Type of PSM	Variables	Average treatment effect on the treated group (ATT)	t-value
Radius Matching	<i>R&D</i>	0.267	5.01
	<i>PATNUM</i>	64.957	3.32
	<i>PATIPC</i>	11.472	4.21
Radius Matching	<i>R&D</i>	0.300	6.86
	<i>PATNUM</i>	65.894	3.43
	<i>PATIPC</i>	12.741	5.35
Nearest Neighbor Matching	<i>R&D</i>	0.233	4.01
	<i>PATNUM</i>	61.426	3.08
	<i>PATIPC</i>	10.391	3.41

Note: All variables are defined in **Table 1**.

Table 8 Result of the 2SLS Regression (the second stage)

	Model (1)		Model (2)
	<i>PATNUM</i>	<i>PATIPC</i>	<i>R&D</i>
	(1)	(2)	(3)
<i>R&D_background</i>	0.327*	1.134***	1.294***
	(1.71)	(4.57)	(5.90)
<i>Dual</i>	-0.102*	-0.051	-0.168**
	(-1.91)	(-0.74)	(-2.73)
<i>Board</i>	-0.027*	-0.032	0.035*
	(-1.66)	(-1.53)	(1.93)
<i>State</i>	0.127**	0.287***	0.022
	(2.09)	(3.64)	(0.32)
<i>Cash</i>	0.446***	0.434***	0.604***
	(19.81)	(14.82)	(23.33)
<i>Lev</i>	1.238***	0.111	1.149***
	(8.12)	(0.56)	(6.56)
<i>Firm FE</i>	Yes	Yes	Yes
<i>Year FE</i>	Yes	Yes	Yes
<i>Cons</i>	-6.199***	-4.657***	4.072***
	(-12.72)	(-7.35)	(7.28)
<i>Adj-R²</i>	0.208	0.187	0.254
<i>Obs.</i>	3,535	3,535	3,535

Notes: t-value is included in the parentheses. *, **, and *** indicate statistical significance at 10 per cent, 5 per cent,

and 1 per cent levels, respectively. Firm and year fixed effects (FE) estimators are used in the panel regression. The

results are qualitatively identical when a pooled data model is used. All variables are defined in **Table 1**.

Table 9 Result of the Heckman Two-stage Model Test (the second stage)

	Model (1)		Model (2)
	<i>PATNUM</i>	<i>PATIPC</i>	<i>R&D</i>
	(1)	(2)	(3)
<i>R&D_background</i>	0.110*	0.213***	0.112**
	(1.89)	(3.10)	(2.51)
<i>Imr</i>	-1.796	-4.793	-2.098
	(-0.50)	(-1.16)	(-0.78)
<i>Dual</i>	0.454	0.973	0.444
	(0.64)	(1.18)	(0.83)
<i>Board</i>	0.020	0.070	0.010
	(0.28)	(0.82)	(0.17)
<i>State</i>	-0.103	-0.032	-0.031
	(-0.57)	(-0.16)	(-0.23)
<i>Cash</i>	0.289***	0.218**	0.238***
	(3.38)	(2.22)	(3.74)
<i>Lev</i>	1.497*	2.193**	1.290*
	(1.67)	(2.12)	(1.92)
<i>Firm FE</i>	Yes	Yes	Yes
<i>Year FE</i>	Yes	Yes	Yes
<i>Cons</i>	-1.999	0.338	13.955***
	(-0.62)	(0.09)	(5.76)
<i>Adj-R²</i>	0.192	0.177	0.368
<i>Obs.</i>	3,535	3,535	3,535

Notes: t-value is included in the parentheses. *, **, and *** indicate statistical significance at 10 per cent, 5 per cent, and 1 per cent levels, respectively. Firm and year fixed effects (FE) estimators are used in the panel regression. The results are qualitatively identical when a pooled data model is used. All variables are defined in **Table 1**.

¹ A study close to our study is the van de Wal et al. (2020) that focuses on CEO research orientation and examines its impact on firms' innovation outcomes. Another study close to our study is the Islam and Zein (2020) study examining the impact of CEOs with hands-on innovation experience as inventors on corporate innovation.

² See more details at <https://deloitte.wsj.com/cio/2019/10/30/china-emerges-as-global-tech-innovation->

[leader/](#) and https://sponsored.bloomberg.com/news/sponsors/hsbc/china-emerges-as-a-global-innovation-hub/?adv=7024&prx_t=zjYDAAAAAAFEANA.

³ See more details at https://www.wipo.int/pressroom/en/articles/2020/article_0005.html.

⁴ See more details at https://www.wipo.int/ipstats/en/statistics/country_profile/profile.jsp?code=CN.

⁵ Our sample ends in 2017 due to the availability of data on innovation outcomes, which are dependent variables in this study.

⁶ See more details at <https://hbswk.hbs.edu/item/what-is-managements-role-in-innovation>.

⁷ According to the current rules and guidance on delisting in China, which are specified by China's Company Law and Securities Law, a listed firm that experiences two consecutive annual losses, will be labelled 'special treatment (ST)'; moreover, it is 'facing imminent danger of delisting unless they return to profitability after reporting two consecutive annual losses.' If the firm continues to experience a loss in the third year, it will receive a delisting risk warning from the stock exchange; then, a '*ST' label will be put before the firm's stock name to distinguish it from other stocks. Subsequently, if the firm continues to generate losses, its listing qualification can be suspended or even terminated.

⁸ See more details from <http://www.wind.com.cn/En/> on *WIND* and <https://us.gtadata.com/#/index> on *CSMAR*.

⁹ See more details about these databases on <https://www.en-cnpr.com/index.jsp>, <https://www.epo.org/>, and <https://www.uspto.gov/>, respectively.

¹⁰ IPC 'has as its primary purpose the establishment of an effective search tool for the retrieval of patent documents by intellectual property offices and other users, in order to establish the novelty and evaluate the inventive step or non-obviousness (including the assessment of technical advance and useful results or utility) of technical disclosures in patent applications'. A complete classification symbol, which

‘represents the whole body of knowledge regarded as proper to the field of patents for invention’. If a single patent tends to be fundamental and generalisable, which means the patent can be used in many fields, then many IPC will be applied (Guide to the International Patent Classification, 2020).

¹¹ 465 out of 835 firms in our sample have top executives (either chairman or CEO or both) with R&D background. 375 firms have chairman with R&D background, among which 173 firms are led by chairman with experience in R&D from universities or R&D-related institutes and 312 firms are led by chairman with experience in R&D from firms. In contrast, 379 firms have CEO with R&D background, among which 153 firms are led by CEO with experience in R&D from universities or R&D-related institutes and 331 firms are led by CEO with experience in R&D from firms. There are 285 sample firms that have both chairman and CEO with R&D background.

¹² Results of these robustness tests are not reported for brevity, but available upon request.