Linking Government R&D Subsidies and Innovation Performance: A Chain-mediating Role of R&D Investment and Technological Collaboration

Xingxiu Wang[a] and Huiying Jiao
School of Management, Changchun University, Changchun, China

Keywords: Innovation Performance, Government R&D Subsidies, Technological Collaboration, R&D Investment, Chain-Mediating Role.

Abstract: This paper aims to probe how government R&D subsidies relate to innovation performance. The authors examined R&D investment and technological collaboration as mediators of relationship between government R&D subsidies and innovation performance. The paper opted for a time-lagged research design to test hypotheses with data covering 483 high-tech listed firms' data in China from 2007 to 2019. STATA and the PROCESS macro in SPSS are used in regression analysis. The results show that R&D subsidies are positively related to firms' innovation performance. The relationship is mediated by R&D investment and technological collaboration. Furthermore, R&D investment is positively related to technological collaboration, there is a chain-mediating relationship among R&D subsidies, R&D investment, technological collaboration and innovation performance. This paper constructs a theoretical framework to specifies the process through which R&D subsidies affects firms' innovation performance to expand understandings of R&D subsidies, which further provides practical value to administrative staffs and policymakers for formulating innovation strategies and R&D subsidies decisions more effectively.

1 INTRODUCTION

The fast growth model of China's economy has been replaced by a high-quality development one recently. It has been generally acknowledged that technological innovation exerts a major function on keeping firms' sustainable development and is the engine of high-quality economic development. In order to raise firms' enthusiasm for technological innovation, China's government subsidizes their research and development (R&D) programs by increasing its intensity of funding continuously (Liu, et al., 2021).

A considerable number of studies tested the associations between R&D subsidies and firms' innovation performance (Yi, et al., 2021; Gao, et al., 2021). Some studies found evidence indicating positive innovation performance effects linked to government R&D subsidies (Wu, et al., 2020, Xu, et al., 2021). Other studies reported that government R&D subsidies distorted factors' price in the process of innovation, resulting in rent-seeking (Gao, et al., 2021, Zhang 2019). In order to obtain public subsidies, some companies may ignore the actual and emerging needs of innovation, which has a crowding out effect on private R&D capital contribution (Zhang, 2019, Yu, et al., 2016). In recent studies, from a perspective of contingency, researchers found the underlying value to discover the factors influencing the link between R&D funding and firms' innovation performance (Gao, et al., 2021). The local R&D financial assistance and specialized industrial agglomeration have been regarded as potentially crucial elements in mitigating the influence of R&D subsidies for innovation performance (Gao, et al., 2021).

Previous literature postulated that a direct link exists between government R&D subsidies and innovation performance. However, few studies have explored how government R&D subsidies relate to innovation performance. In general, R&D investment can be stimulated by government R&D grants, which

[a] https://orcid.org/0000-0003-3319-7850

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also positively influence innovation performance, thus some empirical studies found that R&D investment is the link between R&D funding and innovation performance (Liu, et al., 2021, Xu, et al., 2021, Cerulli, et al., 2015). But existing researches chiefly direct attention to the incentive mechanism of R&D financial support. In fact, R&D subsidies can be regarded as dual signals during the innovation process (Bianchi, et al., 2019). Therefore, numerous investigations and studies are needed to reveal the mechanism of how government R&D subsidies affect firms' innovation performance.

We expand the work on the inner influencing mechanism of R&D subsidies on innovation performance in this article. We suggest that R&D subsidies have a positive effect on innovation performance. Furthermore, we expect that R&D investment and technological collaboration are potential mechanisms for explaining the association between government R&D subsidies and innovation performance. R&D investment is more likely to improve technological collaboration of firms, thereby R&D financial allowances will relate indirectly and effectively to innovation performance via the chain-mediating role of R&D investment and technological collaboration. Using panel data on China's 483 high-tech listed firms from 2007 to 2019, we demonstrate the influencing mechanism of R&D subsidies on innovation performance.

Our research extends the previous literature in two aspects. Based on what we have learned, this is the first research that combines R&D investment and technological collaboration to explain how government R&D subsidies create value for firms' innovation. Compared to other studies on government R&D subsidies (Gao, et al., 2021, Wu, et al., 2020, Yu, et al., 2016), our research demonstrates that R&D investment and technological collaboration are essential factors in enabling companies to reap the benefits of R&D subsidies. Several researches have started to take the mediating role of R&D investment into account (Xu, et al., 2021). Nevertheless, they ignore the signalling of R&D subsidies will encourage technological collaboration (Chapman, et al., 2018, Kim, et al., 2021), which may play the potential mediating role. In addition, new evidence has been provided to indicate that the effects of R&D subsidies on corporate innovation performance are positive in this paper. The main framework of our study is arranged as follows. The very next part shows the theoretical foundation for probing the connections among R&D subsidies, R&D investment, technological collaboration and innovation performance. Then, data, methods, consequences of the study are described in detail. At last, the conclusion part is given.

2 THEORY AND HYPOTHESES

2.1 Government R&D Subsidies and Innovation Performance

As competition between countries becomes fiercer, the importance of technological innovation becomes more and more prominent. Technological innovation behaviours have been strongly supported by governments in most countries, and the relevant policies are tilted towards innovative firms, and the most important is the subsidy of R&D activities. Government R&D assistance exerts the following multiple influences on firms' technological innovation. One is to provide direct financial support to reduce R&D costs. Public R&D funding can be regarded as an incentive policy, which gives free financial support to firms' technological innovation activities (Chapman, et al., 2018). Bérubé and Mohnen (2009) showed that R&D subsidies motivate corporations to introduce more new products. The second is to transmit signals and improve innovation success rates. Acting as a "stamp of approval", the award of Government R&D subsidies is a signal to distinguish firms from their competitors (Bianchi, et al., 2019). R&D financial support will enhance the attractiveness of enterprises' innovation projects, appeal outstanding technical talents to join in and provide access to other innovative factors, so as to improve the success probability of innovation. Third, it will ease the financing constraints. Yang et al. (2021) pointed out that if engaging in R&D activities actively, firms face lower financing costs in the bond market. Government R&D subsidies provide important signals to financial institutions to identify firms' technological innovation ability, thus reducing firms' financing cost via financial support for technological innovation. In addition, R&D subsidies are also one of the signals for consumers to measure product quality in product markets, improving the competitiveness of firms in the market and forming a virtuous circle. There is no denying that R&D subsidies may lead to adverse selection effect due to rent-seeking, encroachment and other issues. However, in general, the government R&D subsidies have clear categories of subsidies and higher application thresholds, so the probability of reverse selection effect is low on the whole. Therefore, the public R&D funding can promote the efficiency of corporate innovation programs. Using data from

Germany, Plank and Dubliner (2018) found public R&D subsidies enhance firms' innovation. Thereby we put forward the following hypothesis: H1. Government R&D subsidies have a positive impact on innovation performance.

2.2 The Mediating Role of R&D Investment

As special assets accumulate, firms' private investment in R&D is conducive to the creation of knowledge, thus improving their competitive advantage in the market. Firms' R&D investment is influenced by government R&D subsidies through the following means. First, it has competitive effects on firms' innovation activities. To apply for government R&D subsidies, enterprises must meet the threshold, so they need to improve their competitiveness, and the simple and direct way is to raise the amount of R&D capital. In addition, the awarding of public R&D grants ought to be more observable to outsiders, so as to avoid information asymmetry. Public R&D subsidies draw the government's attention to key industries and technical areas, which will induce firms to increase investment in R&D projects and make the market participants to form a positive expectation, changing the expected return of firms in related fields. Third, R&D subsidies are also an important way to help firms share the risk of technological innovation, thus increasing firms' enthusiasm to provide capital to R&D projects (Cerulli, et al., 2015). The improvement of R&D investment gives fiscal guarantee to technological innovation. Chen (2021) also confirmed that firms' R&D investment is a crucial factor to improve the performance of technological innovation. Some previous studies have indicated that firms' R&D investment is a critical pathway of public R&D funding on innovation performance (Xu, et al., 2021, Cerulli, et al., 2015). For the above reasons, we come to the next hypothesis: H2. Firms' R&D investment mediates the relationship between government R&D subsidies and innovation performance.

2.3 The Mediating Role of Technological Collaboration

As far as the firm itself is concerned, the organizational boundary is becoming more and more blurred, the knowledge flow is more frequent, and it becomes a common phenomenon to establish technological collaboration with partners and enhance innovation capacity using external intellectual capital due to increasing technical complexity. In addition to R&D investment, public R&D funds will also affect technological innovation by promoting technical collaboration. On the one hand, public R&D funds often favour unconventional or challenging innovation projects, which will urge firms to search and acquire knowledge in multiple technology areas and increase the diversity of technical knowledge (Chapman, et al., 2018). In order to improve the probability of success, firms not only need to cooperate with different types of partners, but also should communicate effectively to reduce the costs of collaboration. On the other hand, R&D subsidies provide funding and other potential resources to support various technological collaboration activities. Bianchi et al. (2019) proposed the twofold signalling effect of public R&D funds, which provides correlative personal information about firms' quality and innovation potentiality. Therefore, public R&D funding provides more opportunities for enterprises to obtain external financing and work with high-quality partners (Chapman et al. 2018, Mo et al. 2020). In addition, the greater the intensity of R&D subsidies, the greater the importance or quantity of projects financed. This will facilitate the identification, absorption and application of external knowledge in related technical fields and enhance the intensity of technological collaboration. The rise in the intensity of technological collaboration will further improve firms' innovation performance (Kim, et al., 2021). Accordingly, we put forward the third hypothesis: H3. Technological collaboration mediates the relationship between government R&D subsidies and innovation performance.

2.4 The Chain-Mediating Role of R&D Investment and Technological Collaboration

Literature on technological collaboration demonstrated that firms' R&D investment improves technological collaboration from many aspects (Cerulli, et al., 2015). First, it avoids information asymmetry. There is a widespread problem of information asymmetry during the process of technological collaboration, because firms know more about their own resources, information, and capabilities than their partners. At this point, firms with higher quality can signal that they are better than their competitors by increasing R&D investment. By observing firms' innovation capabilities, partners can identify firms' quality and increase the possibility of collaboration. Second, it enhances the confidence in

successful technological collaboration and boosts firms' attractiveness. Innovation is the source of firms' sustainable development, big R&D investments show their confidence to promote innovation vigorously, thereby enhancing partners' enthusiasm in technical collaboration. Third, it improves firms' absorption capacity. The intensity of technical collaboration depends on the individual absorption capacity of the members of the firm (Laursen, Salter, 2014). Absorption capacity is a by-product of previous innovation activities and problem solving; stronger innovation input means that enterprise innovation activities are more active and experienced. This helps to recognize and acquire external knowledge that is valuable to technological innovation as well as further improve firms' practices and processes to analyse and interpret external information, which will exert positive impact on technical collaboration and improve innovation performance. Accordingly, we come up with the subsequent hypothesis: H4. R&D investment and technological collaboration will play a chain-mediating role in the relationship between government R&D subsidies and innovation performance.

3 DATA AND MEASURES

3.1 Data

High-tech firms have strong willingness to innovate and participate in innovation activities frequently, which is the focus of public R&D funds in China, so we collect the firm-level data set of the study of listed high-tech companies on the Shanghai and Shenzhen stock exchanges. Among all listed firms, a total of 3,083 firms were identified as high-tech enterprises covering the period of 2001-2019. In order to avoid common research bias, we clean the data by following steps. First, the study excludes high-tech firms whose information disclosure is incomplete. Second, we rule out firms that are treated by ST and *ST. Third, listed firms in the financial insurance category are precluded. Finally, we also exclude firms with a large number of missing observations and outliers, i.e. firms with an asset-liability ratio greater than or equal to 1. After data cleaning, the data of 483 high-tech listed firms are obtained between 2007 and 2019. These firms are distributed in 16 industries, including the computer and electronic product manufacturing industry, electrical equipment manufacturing industry, etc. Research data consist of firms' basic data and technological collaboration data. Basic data are related to R&D expenses, R&D subsidies, asset-liability ratio, etc. over the years, which is collected and organized through the CSMAR database. Government R&D subsidies come from details of government subsidies in financial statements and are collected manually. According to the research of Gong and Zhu (2021), if the title of a subsidies project contains any of the following words, namely, "research and development", "patents", "technological innovation", "technological transformation", "independent innovation", "copyright", "research", "new products", "science and technology", "industrial innovation", "industrial upgrading", "knowledge copyright", "technical standards", "design specifications", "development", "high-tech", "gazelle", "Ph.D", the project is considered to be awarded government R&D subsidies. Technological collaboration data relevant to the intensity of technological collaboration are collected and calculated manually, mainly through the patent search and analysis system, which belongs to the State Intellectual Property Office in China (CNIPA). First, the sample firms' patent application data are retrieved by regular means from 1 January 2001 to 31 December 2020, of which a total of 33764 co-patent applications are collected, and the number of firms' partners is counted to calculate the intensity of technological collaboration. In addition, continuous variables are winsorized at quantiles of 1% and 99% to avoid the effects of extreme values.

3.2 Measures

Dependent variable: innovation performance (Inno). Patents are the main objective index of technological innovation output. They are classified into three kinds, i.e. design, utility model and invention in China. The application time of invention is long due to the stage of substantive examination; thus its protection time is longer than that of others. Correspondingly, the annual fee and agency cost are high. Therefore, consistent with the existing research (Zhang 2019), the study treats the number of invention patent applications as the variable representing innovation performance.

Independent variable: Government R&D subsidies (RD_G). According to Bianchi et al. (2019), it can be measured by two methods. One is a dummy variable; if a firm is awarded government R&D financial assistance, the dummy variable equals 1, otherwise 0. The other one is the logarithms of one plus total amount increased through R&D funds; the greater the value, the more R&D subsidies firms receive. The study mainly adopts the second method.

Mediator variables: R&D investment (RD_F) and technological collaboration (Depth). Following the practice of existing research (Xu, et al., 2021), R&D investment is evaluated by the logarithms of one plus total amount of enterprise's R&D expenses, which is R&D intensity essentially. Following Yang et al. (2019), we adopt technological collaboration depth as a proxy for technological collaboration, which is evaluated by the average number of co-patent applications.

Consistent with previous literature (Liu, et al., 2021, Xu, et al., 2021, Bianchi, et al., 2019, Yang et al. 2019), this study chooses 11 control variables, i.e. firm age (Age), firm size (Size), etc., which are demonstrated in Table 1.

Table 1: Variables and Their Measurements

Variable Name	Symbol	Measurable Indicator
Innovation performance	Inno	Number of patent applications for inventions
Government R&D subsidies	RD_G	Log of (1+ total amount raised through R&D subsidies)
R&D investment	RD_F	Log of (1+ total R&D expenses)
Technological collaboration	Depth	Average number of co-patent applications
Firm size	SIZE	Log of the total asset
Firm age	AGE	Years since a firm was funded
Leverage	LEV	Ratio of total debt to total assets
Return on total assets	ROA	Ratio of net profit to total average assets
Export	Export	The dummy variable equals 1 if the product of firm is exported abroad, otherwise 0
Firm group	Group	The dummy variable equals 1 if the company belongs to a firm group, otherwise 0
Institutional environment	Institution	Market-oriented total index score (Fan et al., 2018)
Market concentration	HHI	Heffendahl Hirschman index
State-owned enterprises	SOE	The dummy variable equals 1 if the company is state-owned, otherwise 0
Industry	Industry	According to the technology intensity classes of OECD, there are six industry dummies, i.e. high-tech manufacturing, high medium-tech manufacturing, etc. (Herstad et al., 2015)
Year	Year	Dummy variables for the years 2008–2019

3.3 Empirical Results

The descriptive statistics of all variables are shown in Table 2. The mean value of innovation performance is 21.547, its standard deviation value is 86.622, demonstrating that the innovation output of Chinese high-tech firms is in its infancy with a big gap between high and low. The mean value of R&D subsidies is 10.382 with a maximum of 18.390 and a minimum of 0, which suggests that government R&D subsidies is at a relatively top-level stage, but there is also a big gap among firms. The average R&D investment is 18.037 with a minimum of 15.251 and a maximum of 21.512, displaying that the intensity of R&D is comparatively balanced. The mean value of technological collaboration is 1.329 with a maximum of 26.125 and a minimum of 0, indicating that technological collaboration depth is at a low level with a big gap between high and low.

Table 2: Descriptive Statistics.

Variable	Obs.	Mean	SD	Min	Max
Inno	5 205	21.547	86.622	0.000	1 919.00
RD_G	4 757	10.382	6.742	0.000	18.390
RD_F	3 722	18.037	1.253	15.251	21.512
Depth	5 206	1.329	3.689	0.000	26.125
SIZE	4 722	21.973	1.106	19.902	25.093
AGE	5 206	17.269	5.468	7.000	32.000
LEV	4 722	40.731	18.997	4.587	81.856
ROA	4 724	0.046	0.047	-0.114	0.194
Export	4 136	0.582	0.493	0.000	1.000
Group	4 721	0.962	0.191	0.000	1.000
Institution	4 724	7.133	3.014	0.000	10.780
HHI	4 723	0.099	0.100	0.015	0.651
SOE	4 724	0.365	0.481	0.000	1.000

Note: Obs. denotes number of countries in the baseline model. SD denotes standard deviation.

Table 3 reports the regression analysis results through the causal-step method (Model 1 to 5). The coefficient of RD_G shows that R&D subsidies can improve firms' innovation performance in Model 1 ($b=0.009$, $p<0.01$), which provides support for Hypotheses 1. Model 2 indicates that the R&D subsidies increase the R&D investment ($b=0.004$, $p<0.05$). Meanwhile, the coefficient of RD_F is 0.080 ($p<0.5$) in Model 5, indicating that R&D investment promotes innovation performance. Thus, Hypotheses 2 is confirmed. Model 3 implicitly assumes that R&D subsidies have a constructive effect on technological collaboration ($b=0.014$, $p<0.01$). The coefficient of Depth in Model 5 suggests that technological collaboration benefits innovation performance ($b=0.059$, $p<0.01$). Therefore, technological collaboration is an important pathway for R&D subsidies to influence innovation performance,

providing, Hypotheses 3 is confirmed. Model 4 demonstrates that R&D investment undoubtedly promotes the depth of technological collaboration (b=0.132, p<0.05). The above regression results together display that R&D investment and technological collaboration play a chain-mediating role in the links between government R&D subsidies and firm innovation performance. Therefore, Hypotheses 4 is confirmed.

Table 3: The Mediating Role of R&D Investment and Technological Collaboration

Variable	Inno	RD_F	Depth		Inno
	Model 1	Model 2	Model 3	Model 4	Model 5
RD_G	0.009*** (3.04)	0.004** (2.28)	0.014*** (2.94)	0.006 (1.06)	0.004 (1.22)
RD_F				0.132** (2.10)	0.080** (2.41)
Depth					0.059*** (16.96)
Constant	-0.364 (-0.50)	4.715*** (6.16)	-11.128*** (-10.36)	-10.064*** (-7.33)	-0.742 (-0.99)
$SIZE_{t-1}$	-0.035 (-1.05)	0.590*** （19.95）	0.400*** (8.08)	0.274*** (3.34)	-0.098** (-2.29)
AGE_{t-1}	-0.011 (-1.30)	-0.035 （-0.85）	0.008 (0.71)	-0.000 (-0.00)	-0.006 (-0.85)
LEV_{t-1}	0.002 (1.19)	0.003** (2.23)	0.002 (0.67)	0.002 (0.54)	0.004** (1.99)
ROA_{t-1}	3.075*** (6.53)	3.284*** (11.56)	4.207*** (5.00)	3.721*** (3.62)	2.067*** (4.08)
$Export_{t-1}$	-0.086 (-1.64)	-0.087** (-2.28)	0.114 (1.34)	-0.026 (-0.25)	-0.085 (-1.57)
$Group_{t-1}$	0.105 (0.91)	-0.021 (-0.29)	0.098 (0.37)	0.023 (0.07)	0.137 (1.08)
$Institution_{t-1}$	0.013 (0.57)	-0.021 (-0.78)	0.071** (2.22)	0.083** (1.98)	0.050** (2.33)
HHI_{t-1}	-0.486 (-1.59)	0.592*** (3.11)	-0.591 (-1.23)	-0.207 (-0.32)	-0.301 (-0.087)
SOE_{t-1}	0.295*** (4.19)	0.183* (1.72)	0.471*** (4.43)	0.262* (1.88)	0.222*** (3.03)
Year	Yes	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes	Yes
Obs.	3 584	2 985	3 693	2 077	2 985
F	-	117.01***	-	-	-
Wald	387.44***	-	240.76***	127.91***	594.33***

Note: (i) The values in parentheses are the p-values. ***, ** and * display significance at the level of 1%, 5% and 10%, respectively, (ii) Model 2 was estimated by a regression model for panel data, the other models were estimated by the negative binomial models for panel data, whether to choose a fixed effect model or a random effect model were determined by the Haussmann test.

Table 4 depicts the results from the bootstrap test using Process (Hayes) for SPSS with 5000 samples and a 95% confidence interval. The direct effects of R&D subsidies fail to be statistically significant and is reported in Table 4. R&D investment and technological collaboration appears as valid mediation mechanisms between R&D subsidies and innovation performance, consistent with the conclusion of the causal step method. These findings strongly support that public R&D subsidies have indirect influence on innovation performance through increases in R&D investment and technological collaboration. In addition, Table 4 confirms that R&D subsidies promote R&D investment, R&D investment has a progressive influence on technological collaboration, thus increasing firms' innovation performance. Consequently, we find support for H4, which predicts the chain-mediating role of R&D investment and technological collaboration.

Table 4: Bootstrap Test Results.

The mediation path	Indirect effects	Confidence interval (95%)		Direct effect
		Lower limit	Upper limit	
RD_G—RD_F—Inno	0.229	0.124	0.361	0.305 (1.24)
RD_G—RD_F—Depth—Inno	0.046	0.022	0.085	
RD_G—Depth—Inno	0.165	0.007	0.373	
Total mediation effect	0.440	0.234	0.698	

Note: The values in parentheses are the p-values.

3.4 Robustness Checks

Three important robustness checks were conducted, the results for which are shown in Table 5. First, we tested the endogenous problems that may exist between variables using system GMM estimation for dynamic panel data. With leverage, ROA, R&D investment at time t to t-2 as instrumental variables, the coefficient of RD_G_{t-1} is positive and significance (b=1.118, p<0.05), passing the AR (2) test and Hansen test in Model 6. Second, we checked the sensitivity of key variables. With dummy variable as a substitute measure of R&D subsidies, the consequences show that the coefficient of RD_G is positive in Model 7(b=0.131, p<0.01). With the count of licensed patents instead of patent application quantities for inventions in regression, Model 8 shows that the coefficient of RD_G is 0.009(p<0.05). Finally, we replace the negative binomial models with a panel Tobit model, which shows that the coefficient of RD_G is 0.888 in Model 9(p<0.01). In these settings, we obtain the same result of those presented above.

Table 5: Robustness Checks Results.

Variable	Inno			
	Model 6	Model 7	Model 8	Model 9
RD_G_{t-1}	1.118** (2.37)		0.009** (2.44)	
RD_G		0.131*** (2.96)		0.888*** (3.35)
$Inno_{t-1}$	0.774*** (63.02)			
Constant	261.148 （0.91）	-0.460 (-0.63)	-1.179*** (-1.25)	-490.000*** (-7.26)

Control Variables	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes
Obs.	2 247	3 376	3 362	3 693
AR(2)	0.418	-	-	-
Sargan	0.000	-	-	-
Hansen	0.273	-	-	-
Wald	22 879.6***	386.56***	649.97***	267.28***

Note: The values in parentheses are the p-values. ***, ** and * indicate significance at the level of 1%, 5% and 10% respectively. Due to limited layout, coefficients of control variables are not listed here; if you're interested, please contact the corresponding author.

4 CONCLUSIONS

Technological innovation is a fundamental factor to boost the sustainable development of firms. As important public policies, government R&D subsidies support and stimulate firms to innovate continuously, thus raise innovation performance. Our intention in this paper has been to offer an explication on how government R&D subsidies shape firms' likelihood to implement technological innovation. Using panel data from 483 Chinese high-tech listed firms during the period 2007 and 2019, this research estimates a chain-mediated model to investigate the causal connection among R&D subsidies, R&D investment, technological collaboration and innovation performance.

Our findings provide strong support for the assumption that R&D subsidies are conducive to promoting innovation performance, proving the effectiveness of public R&D funding in China. More importantly, this research demonstrates that R&D investment and technological collaboration illustrate part of the process through which enterprises convert the benefits of public R&D funds into enhanced innovation performance. Particularly, the research elaborates three substitute methods that allow businesses to create value from government R&D subsidies. For instance, consistent with previous studies, our results demonstrate that R&D subsidies enhance firms' creativity by affecting their private investment in R&D. Furthermore, technological collaboration plays an important mediating role in the association between government R&D subsidies and innovation performance. In addition, our findings also display that R&D investment and technological collaboration play chain-mediating role through which R&D subsidies have indirect influence on innovation performance. Generally speaking, these conclusions discover new methods through which R&D subsidies drive innovation performance of corporations, which further has implications for the corporation innovation literature from the perspective of signalling theory.

Our results have also implications for practitioners. First, our results point out that public R&D subsidies enhance innovation performance. Therefore, the policy makers have an obligation to keep on providing more R&D funding, firms should actively apply for public R&D subsidies and enhance their utilization efficiency, so as to jointly promote innovation performance. What's more, according to the reported effects of R&D subsidies, it is obvious that firms with reward of state R&D funds should promote the intensity of R&D investment because it not only boosts innovation performance directly, but also plays an indirect role in strengthening technology innovation by technological collaboration. Third, firms should also establish open innovation strategies, make good use of existing R&D resources, increase the enthusiasm of partners, and work together for more challenging technological innovation activities. Finally, drawing on the findings on multiple mediation roles of R&D investment during technological innovation process, for one thing, firms can choose different ways to achieve the goal of improving innovation performance; for another, policy-makers should take notice of the signal transmitted by government R&D funds, and manage them in a targeted manner, so as to increase the effectiveness of public R&D funding.

However, this investigation is not without limitations, and future work may explore the following issues. Firstly, because the data of R&D subsidies are collected manually, the study only selected the effect of the amount of R&D subsidies on innovation performance, but did not classify the specific content of subsidies or funding agencies to explore its impact on innovation; more research is needed in this field. Secondly, considering the availability of data, the research selected high-tech listed companies as research samples, not non-listed enterprises, a deeper analysis with a wider sample is needed too. In addition, this paper only tests the impact of R&D subsidies, R&D investment, technological collaboration on innovation performance, it could be better to recognize other factors with potential effects on how R&D subsidies create value for firms, such as technical cooperation governance, science cooperation and so on.

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