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REGULAR ARTICLE

Opening the box of subsidies: which is more effective for innovation?

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Abstract

Government research and development (R&D) subsidy is one of the main policy instruments to deal with market failure, and its effectiveness has attracted attention increasingly. This study investigates the impact of two types of government R&D subsidies on innovation using the data of Chinese listed enterprises from 2010 to 2016. We find that compared with ex-post rewards, ex-ante grants have a better effect on innovation performance by stimulating private R&D investment. Additionally, the effectiveness of government R&D subsidies is weakened in enterprises engaging in rent-seeking and political connections. This study provides a new perspective for understanding the effect of government R&D subsidies, and the research conclusions are the relevant reference for the government to improve the efficiency of allocating public funds.

Keywords Research and development (R&D) subsidies · Ex-ante grants · Ex-post rewards · Innovation performance

JEL Classification G34 · G38 · H25

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1 Introduction

Strengthening technological innovation is an important way for enterprises to obtain and maintain market competitiveness (Exposito and Sanchis-Llopis 2019; Knight and Cavusgil 2004; Tian et al. 2020; Zhang et al. 2020). However, research and development (R&D) activities for innovation have the attributes of public goods, that is, positive externality and non-exclusivity, which results in the private R&D expenditure tend to be lower than the socially optimal level. In this case, public policies in support of R&D can encourage enterprises to conduct technological innovation for addressing such market failure (Arrow 1962; Choi and Lee 2017). China' s 13th 5-Year Plan (2016–2020) has singled out innovation as one of the top priorities, and heavily subsidized it. From 20http://data.stats.gov.cn09 to 2018, the government funds for R&D have increased from $19.6 billion to $57.4 billion.[1] The R&D subsidies from the government have become a vital financial source for enterprises' innovation activities.

In recent years, the precise effect of R&D subsidies from the government is a much-debated topic. Literature has increasingly emerged that offers contradictory findings. Some studies propose that government R&D subsidies have a positive impact on enterprises' innovation. For example, they narrow the gap between the creator's private profits and social benefits, and alleviate the underinvestment of enterprises in R&D activities (Choi and Lee 2017; Zuniga-Vicente et al. 2014). Also, these subsidies are conducive to attract private financing and bank loans, which stimulate private R&D activities and investment and improve enterprises' innovation and performance (Amoroso 2017; Bai et al. 2019; Barbieri et al. 2020; Cin et al. 2017; Gonzalez and Pazo 2008; Kleer 2010; Li et al. 2019; Sun et al. 2020; Wu 2017). Nevertheless, some research suggests the limitations faced by public funding instruments in promoting innovation (Berrutti and Bianchi 2020). Due to the opacity of enterprises' R&D capabilities, R&D funds from the government may flow into projects that would have been implemented anyway, thus only serve to substitute private R&D expenditure (Antonelli and Crespi 2013; Zhang et al. 2014). Besides, subsidized enterprises tend to over-invest and avoid the government's regulation through earnings management (Chen et al. 2008; He 2016; Hu et al. 2019). More important, these subsidies can be distorted, such as rent-seeking and bureaucratic corruption, which not only leads to the misallocation of funds but also undermines incentives for innovation (Du and Mickiewicz 2016; Khyareh 2019).

Although some existing studies have analyzed the effect of government R&D subsidies on innovation from different perspectives, most of them have not considered the differences in the design of subsidy policies and only regarded R&D subsidies from the government as a whole (Catozzella and Vivarelli 2016; Zhang and Guan 2018; Zhao et al. 2018). It is reasonable to believe that different subsidy designs have different influences on enterprises' innovation, which needs to be further discussed (Bellucci et al. 2019). Specifically, the types and rules of the various

[1] Data source: National Bureau of Statistics of China http://data.stats.gov.cn

R&D subsidies from the government are often decided by local governments, and different R&D subsidies have diverse requirements on the enterprises' innovation achievements (Lee et al. 2014). Hence, this study mainly considers two types of R&D subsidies provided by the government, including ex-ante grants and ex-post rewards.

In this study, we conduct a batch of analyses to explore the impact of different types of government R&D subsidies on enterprises' innovation performance using the data of listed enterprises in China from 2010 to 2016. Our study makes several contributions to the literature. First, to the best of our knowledge, this study may be the first to divide the government R&D subsidies into ex-ante grants and ex-post rewards, and explore their effects on the enterprises' innovation performance. Second, we introduce private R&D investment as an influence channel to examine the relationship between the government R&D subsidies and enterprises' innovation performance, thus providing a potential explanation for the ex-ante grants and ex-post rewards on enterprises' innovation performance. Third, we provide a new sight to investigate the impact of government R&D subsidies on enterprises' innovation performance from the perspective of rent-seeking behavior and political connections. Finally, we also explore the moderating effects of marketization and anti-corruption on the relationship between R&D subsidies and enterprises' innovation performance.

The structure of this study is as follows. Section 2 provides theoretical analysis and develops research hypotheses. Section 3 describes the research design and data sources. Section 4 analyzes the empirical results, including the main results, endogeneity tests, robustness tests, and further analysis, and the final section summarizes the main findings and policy implications.

2 Theoretical analysis and research hypotheses

In this section, we theoretically analyze the relationship between government R&D subsidies and innovation performance, as well as the different effects of ex-ante grants and ex-post rewards. We also discuss the influence channel of private R&D investment and the moderating role of rent-seeking and political connections. On this basis, the research hypotheses of this study are put forward.

2.1 Government R&D subsidies and innovation performance

There are different perspectives on whether government R&D subsidies can stimulate enterprises to innovate. Most studies agree on the positive role of government R&D subsidies on the enterprises' innovation (Bellucci et al. 2019; Guo et al. 2016; Li et al. 2019). When an enterprise receives government R&D subsidies, it exactly increases cash inflows. This, in turn, can narrow the gap between the innovative enterprise's private profits and the social welfare of innovation (Hall 2002; Zuniga-Vicente et al. 2014). Also, government R&D subsidies serve as a positive signal for external potential capital providers. In other words, the subsidized enterprises are

certified as high-quality ones by the government to some extent, which helps make less the information asymmetry and promote later access to debt and equity financing (Li et al. 2019; Wu 2017). Thereby, government R&D subsidies help lessen the marginal costs and risks of R&D, increase private R&D investment, and develop more new technologies and products, thus strengthening the innovation capacity of enterprises (Clausen 2009). Besides, compared with non-subsidized enterprises, government R&D subsidies significantly increase enterprises' R&D intensity and behavioral additionality (Clarysse et al. 2009; Engel et al. 2019; Peteski et al. 2020). Similarly, for start-ups with financing difficulties, government R&D subsidies can become less the uncertainties of R&D investment and exert a significantly positive impact on the enterprises' patent output and earnings (Howell 2017).

However, some studies suggest that government R&D subsidies do not significantly promote enterprises' innovation (Catozzella and Vivarelli 2016; Gonzalez et al. 2005; Gorg and Strobl 2007). From the perspective of resource allocation, there are discrepancies in the goals of the government and enterprises. For profit-maximizing enterprises, the cost of obtaining grants from the government is much lower than the cost of raising funds in the capital market. Due to the lack of systematic reporting and monitoring of subsidy effectiveness (Zhang et al. 2014), government R&D subsidies may be invested in non-innovative activities such as production, and thus making R&D subsidies unable to play a role in promoting enterprises' innovation (Antonelli and Crespi 2013; Hu et al. 2019). Besides, some enterprises will use the government R&D subsidies to carry out innovation activities instead of their R&D investment funds (Gorg and Strobl 2007). As well, government subsidies for R&D can lead to higher costs, such as higher salaries for researchers, which crowd out private funding (OECD 2016). For the government, in order to accomplish political tasks as soon as possible, government officials may assign funds in projects with high expected success rates along with high and fast returns, while ignoring most projects with high social returns, low short-term profit, and much more promising development (Hussinger 2008).

According to the differences in distribution methods and actual eligibility, government R&D subsidies can be divided into two types: ex-ante grants and ex-post rewards. The former is a one-off or multiple grants to support an enterprise's R&D activities in advance. While the latter is a reward for the enterprise's achievements in technological innovation and usually issued after the completion of R&D projects. Following Busom et al. (2014) and Radas et al. (2015), we can compare the ex-ante grants and ex-post rewards from three aspects, including the timing to release subsidies, the requirements for subsidies, and the magnitude of subsidies (see Table 1).

As for the timing of subsidies, ex-ante grants are usually used to provide upfront funding for R&D projects, while ex-post rewards are adopted to reward enterprises after their successful R&D activities. Therefore, to benefit from the ex-post rewards, enterprises must complete R&D achievements, such as patents, new technologies, or new products. However, enterprises need to invest a large amount of capital in the early stage of R&D activities, and they are faced with various risks at this stage (Xing 2019). If enterprises cannot raise enough funds to conduct the required tests, they have to suspend the R&D projects (Li 2011; Zhang et al. 2018). Even if the enterprises have completed the R&D of new products, it is difficult to obtain

Table 1 Comparison between ex-ante grants and ex-post rewards

	Ex-ante grants	Ex-post rewards
Timing	Grants are available before the R&D project begins.	Funds are available after the R&D activity ends.
Requirements	Only R&D projects meeting agency requirements are eligible.	The result of any R&D project is eligible.
	Need to compete with the peers.	No competition (at least partly).
Magnitude	The amount is determined before the R&D project begins.	The amount depends on the success rate of R&D projects.

sales revenue in a short period (Pellegrino and Piva 2020). In particular, small and medium-sized enterprises (SMEs) that cannot afford the high costs and risks of R&D may not engage in R&D activities without ex-ante grants (Gonzalez and Pazo 2008). In this case, compared with ex-post rewards, ex-ante grants can provide financial support to the enterprises' R&D activities in the early stage, and promote the enterprises' innovation performance more effectively.

In terms of the requirements for subsidies, while the results of all R&D projects qualify for ex-post rewards, only those projects exhibiting a high degree of novelty, risk, or spillover capacity may be eligible for ex-ante grants. To obtain ex-ante grants, enterprises must submit an application to the subsidy awarding agency, containing the innovative content, the project's prospect, the technical capability, etc. The agency decides whether to grant its R&D project after screening and ranking the proposals. In contrast, ex-post rewards do not require assessing the innovations' quality by government agencies. Patent subsidies, for example, are available to all patents granted, regardless of their quality or characteristics. In this case, ex-post rewards are more likely to encourage short-term imitative innovations (Du and Mickiewicz 2016), while ex-ante grants are conducive to make long-term fundamental innovations, such as developing new products and services (Le and Jaffe 2017).

With respect to the magnitude of subsidies, although both ex-ante grants and ex-post rewards provide direct financial support for R&D, ex-ante grants possess greater certainty on the extent of such support for enterprises. The subsidized enterprises with ex-ante grants already know how many funds they will obtain before the project starts. In the case of ex-post rewards, it is difficult for enterprises to predict how much will be awarded. Besides, the magnitude and duration of ex-ante grants would be tailored by the government agency according to the particular features of R&D projects. For example, more innovative projects are likely to receive more funds. Hence, ex-ante grants would do more to relieve the financing constraints of R&D, while ex-post rewards can hardly solve the funding dilemma for R&D activities.

Therefore, we hypothesize the following:

Hypothesis 1 *Ex-ante grants have better incentive effects on enterprises' innovation than ex-post rewards.*

2.2 The influence channel of private R&D investment

Based on the previous literature, R&D is an essential determinant of innovation (Gogokhia and Berulava 2020). However, well-understood market failures have led to inadequate private investment in R&D activities (Newell 2010). Therefore, it is necessary to encourage the private sector to increase funds to support enterprises' R&D activities (Choi and Lee 2017). One primary concern is whether the government can actually channel public funds to R&D projects with more significant market failure. If government R&D subsidies only flow into those projects that are likely to yield high private returns and are sure to be implemented, they may largely displace private R&D expenditures and will be hard to induce additional

innovations. Thus, private R&D investment should be regarded as a potential influence channel for the impact of government R&D subsidies on enterprises' innovation performance.

Although both ex-ante grants and ex-post rewards can directly reduce the private costs of investing in R&D, the two types of government R&D subsidies have different effects on stimulating enterprises to increase R&D expenditure. Ex-ante grants are usually designed to support R&D projects with enormous expected social benefits but insufficient expected private returns, especially those that would not be possible without subsidies (Radas et al. 2015). In contrast, ex-post rewards place little attention on the characteristics of R&D projects, which enables enterprises to invest in projects that are easy to obtain ex-post rewards (Busom et al. 2014). Thus, ex-post rewards may be just a substitute for private R&D investment, while ex-ante grants are more likely to supplement or stimulate private R&D expenditure.

Besides, R&D subsidies can alleviate information asymmetry between enterprises and external investors. Due to R&D activities always involve much confidential information and professional knowledge, it is difficult for investors to evaluate the pros and cons as well as expected returns of R&D projects (Wu 2017). Under this circumstance, R&D projects struggle to attract outside investment and are vulnerable to financial distress. R&D subsidies can play the role of certification and send a positive signal of the R&D project's quality to market investors (Cin et al. 2017). Compared with ex-post rewards, the application of ex-ante grants has more strict and comprehensive identification, and ex-ante grants are more able to facilitate subsidized enterprises to attract external investment and increase private R&D expenditure. Therefore, ex-ante grants have a better promotion effect on private R&D investment than ex-post rewards. The former, in turn, can inspire revolutionary and radical innovation, while the latter can only induce marginal or incremental innovation.

Therefore, we hypothesize the following:

Hypothesis 2a *R&D subsidies can influence enterprises' innovation performance by promoting private R&D investment.*

Hypothesis 2b *Ex-ante grants are more capable of stimulating R&D investment than ex-post rewards.*

2.3 The moderating role of rent-seeking and political connections

The central government usually adopts R&D subsidies to guide enterprises to carry out new and promising R&D activities (e.g., clean energy and green materials) (Laincz 2009; Tian et al. 2021). However, local governments have discretion over the criteria, size, and recipients of subsidies according to their strategic objectives (Bertrand et al. 2007; Lee et al. 2014). Notably, the approval of some subsidies may be dominated by individual government officials rather than peer reviewers and experts (Pei 2016). This provides enough incentive for local government officials to seek rents through their relationships with enterprises, especially in developing

countries with weak institutions (Chen et al. 2011; Liu 2020). Furthermore, political connections are also widely used by enterprises when local governments have considerable discretion to grant subsidies (Cai et al. 2011). Because the relationship capital of enterprises plays a vital role in the competition of subsidy objects (Zhao et al. 2018). Lots of evidence have shown that private enterprises can enjoy preferential government treatment and access financial subsidies by establishing political connections (Cheng 2018; Du and Mickiewicz 2016). Likewise, enterprises with political connections are more likely to receive government R&D subsidies than those without political connections, even if some of them are not for R&D (Cumming et al. 2016).

Nevertheless, rent-seeking and political connections produce much explicit and hidden expenses. For example, some enterprises typically use entertainment and travel costs as camouflage expenses that involve connecting with government officials (Cai et al. 2011; Khan et al. 2020). Fake or inflated fees are also presented for illegitimate purposes. Thus, enterprises that pay these fees may obtain more R&D subsidies from the government (Ayyagari et al. 2011). However, all these expenses inevitably "squeeze out" the innovative funds of an enterprise, leading to a reduction in innovation performance (Chen et al. 2011). Meanwhile, to shield themselves from public scrutiny, rent-seeking enterprises have incentives to decrease corporate governance, increase opaqueness, and engage in earnings management. The indirect and long-term costs of rent-seeking and political connections also offset their benefits, thus hindering the enterprises' innovation performance (Liu et al. 2018). Therefore, the effect of government R&D subsidies on innovation performance will be better in enterprises without rent-seeking activities or political connections.

Based on the above analysis, we propose the following hypotheses:

Hypothesis 3a *Both types of R&D subsidies exert a better effect on non-rent-seeking enterprises than rent-seeking enterprises.*

Hypothesis 3b *Both types of subsidies exert a better impact on enterprises without political relationships than those with political connections.*

3 Research design

3.1 Sample and data collection

In this study, we select the enterprises listed on China's Growth Enterprise Market (GEM) from 2010 to 2016 as the sample. The main reasons are as follows: First, the GEM was launched by China's Shenzhen Stock Exchange in October 2009 and aims at providing fundraising opportunities for SMEs with excellent growth potential and strong innovation motivation. Second, compared with those listed on the main board,

enterprises listed on the GEM are more dependent on government R&D subsidies. Because they are typically smaller and younger, and most of them are engaged in high-tech sectors (Li and Hou 2019).[2] We can discover a more obvious relationship between R&D subsidies and enterprises' innovation in these enterprises. Finally, the Chinese government revised the *Accounting Standards for Enterprises* in 2017, requiring that unreceived government subsidies be included in enterprises' financial statements. If our sample contains data for 2017 and beyond, it may affect the final results. Hence, we take the data of China's GEM enterprises from 2010 to 2016 as the sample.

We also preprocessed the data according to the following criteria: (1) Removing enterprises with incomplete metrics and data; (2) excluding enterprises that have undergone IPOs in that year to eliminate the impact of the enterprise's listing on financial data; (3) excluding the state-owned enterprises, because they undertake a large number of social and political tasks, and there is an inherent principal-agent problem (Sun et al. 2020). The main variables are tailed off at a 1% level to exclude the influence of outliers. Besides, all data are collected from authoritative Chinese databases to ensure reliability and authenticity, such as the CSMAR database[3] and the RESSET database.[4] After preprocessing, we construct an enterprise-year panel dataset, including 1010 enterprise-year separate observations.

3.2 Variables

3.2.1 Explained variable: innovation performance

Although some studies use innovation inputs such as R&D expenditure and the number of researchers to evaluate the enterprises' innovation performance (Cin et al. 2017; Gonzalez and Pazo 2008; Zuniga-Vicente et al. 2014), this study focuses more on assessing whether government subsidies will induce additional innovation outputs. The reason is that innovation output is probably the ultimate goal of most government subsidies to support R&D activities (Bronzini and Piselli 2016). R&D subsidies would increase the level of innovation outputs even when innovation inputs are kept constant. For example, R&D subsidies might lead subsidized enterprises to make riskier choices and engage in revolutionary and fundamental innovation activities without increasing innovation inputs in quantitative terms (Bronzini and Piselli 2016). Therefore, we adopt the patent data as the proxy variable of enterprises' innovation output to conduct a series of empirical analyses.

The patent administration department publicly grants a patent based on its novelty and utility (Tian et al. 2020). Patent data can objectively reflect the progress of innovation and is an essential indicator to measure innovation performance (Fang et al. 2017;

[2] The industry distribution of the sampled enterprises is shown in Appendix A. In this study, 79.1% of the sampled GEM enterprises belong to high-tech industries defined by the China National Bureau of Statistics.

[3] CSMAR database: http://www.gtarsc.com/.

[4] RESSET database: http://www.resset.cn/.

Rong et al. 2017). However, different types of patents represent different levels of innovation. The *Patent Law of the People's Republic of China* stipulates that patents are divided into three types: invention, utility model, and design. The invention-type patent refers to new technical schemes proposed for a product, method, or product's improvement. This type of patent represents the core technical achievements of an enterprise and is regarded as the innovation of a high technical level. According to the data of China's National Intellectual Property Administration, the success rate of invention patents is only 26.25% in 2017, and it is the lowest among the three types. In contrast, the utility model and design-type patents are regarded as the innovation of a low technical level. Therefore, there are reasons to believe that the application number of invention patent (*Patent*) is a better indicator to measure the innovation performance of enterprises in China.

3.2.2 Explanatory variables: government R&D subsidies

In this study, we divide the explanatory variables of government R&D subsidies into ex-ante grants (*Subgrant*) and ex-post rewards (*Subaward*). According to the guidelines of the subsidy scheme, government R&D subsidies are allocated to enterprises' R&D activities, excluding subsidies irrelevant to innovation activities of enterprises, such as poverty alleviation and demolition compensation. Among them, ex-post rewards are rewards for the technological innovation achievements of enterprises, including patent application subsidy, intellectual property subsidy, new product subsidy, science and technology award, and other innovation awards. While ex-ante grants are assigned for supporting the enterprises' R&D activities, and mainly include funds for national and provincial science and technology programs, subsidies for technological transformation and upgrading, subsidies for technology commercialization and equipment and systems purchase, and other R&D funds.

3.2.3 Mediating variable: private R&D investment

Private R&D investment (*RD*) is one of the most critical channels for the impact of government R&D subsidies on enterprises' innovation performance, and thus we choose it as the mediating variable (Costa-Campi et al. 2014). Private R&D investment is defined as the difference between enterprises' total R&D expenditure and government R&D subsidies, then divided by its total assets at the beginning of the observation year.

3.2.4 Moderating variables: rent-seeking and political connections

Rent-seeking (*Rent*): Referring to the studies of Liu et al. (2018), rent-seeking is defined as a dummy variable. If the excess management cost is greater than 0, indicating that the enterprise has rent-seeking behavior, and this variable will be equal to one. Otherwise, it is equal to zero when the enterprise is deemed to have no rent-seeking behavior. The excess management cost is the residual from the following regression equation:

$$ME_{it} = \gamma_0 + \gamma_1 Revenue_{it} + \tau_{it} \quad (1)$$

where *ME* is the enterprise's management expense divided by its total assets, *Revenue* is its main business income divided by its total assets. The regression allows us to exclude the impact of the enterprise's normal business on total management expenses to derive a proxy for enterprise rent-seeking.

Political connections (*Political*): According to a definition provided by Deng et al. (2018) and Fisman and Wang (2015), political connections are defined as a dummy variable. Specifically, if the chairman or CEO of a listed enterprise is a former or current government official (only positions above division level), a National People's Congress (NPC) deputy or member of the Chinese People's Political Consultative Conference (CPPCC), the value of political connections will be equal to one; otherwise, it is set as zero.

3.2.5 Control variables

According to the studies of He and Tian (2013) and Hellmann and Thiele (2011), at the enterprise level, we control the following variables: enterprise size, return on equity, annual capital expenditure, equity restriction, the ratio of institutional shareholding, the ratio of independent directors, and salary incentive.

(1) Enterprise size (*Size*). It is expressed as the natural logarithm of the ending balance of total assets.
(2) Return on equity (*ROE*). It is expressed as the ratio of net profit to average shareholders' equity.
(3) Annual capital expenditure (*Capital*). It is expressed as the natural logarithm of the enterprise's capital expenditures.
(4) Equity restriction (*Equ*). It is expressed as the ratio of the total shareholding of the second to fifth largest shareholder to that of the largest shareholder.
(5) The ratio of institutional shareholding (*Ihld*). It is expressed as the sum of the shareholding ratio of institutional shareholders among the top ten shareholders.
(6) The ratio of independent directors (*Inder*). It is measured as the proportion of independent directors to the total number of directors.
(7) Salary incentive (*Pay*). It is expressed as the natural logarithm of the total annual salary of directors, supervisors, and senior executives.

Table 2 shows the details of these variables.

3.3 Models

According to the studies of Fiebig (2007), the amount of patent applications is taken as a non-negative integer. Even if a logarithmic transformation is performed on such counting variables, the OLS regression will be biased. Therefore, we construct a negative binomial regression model for testing our Hypothesis 1. The regression model is as follows:

Table 2 Description of variables

Types	Variables	Symbols	Definitions
Explained variable	Innovation performance	*Patent*	Number of invention-type patent applications
Explanatory variables	Ex-post rewards	*Subaward*	Sum of rewards issued after the certain innovation output/main business income
	Ex-ante grants	*Subgrant*	Sum of grants issued once or several times for supporting corporate R&D activities/main business income
Mediating variable	Private R&D investment	*RD*	(Total R&D expenditure - R&D subsidies)/total assets at the beginning of the observation year
Moderating variables	Rent-seeking	*Rent*	If the excess management cost is greater than 0, this is represented by 1; otherwise, signified by 0
	Political connections	*Political*	If chairman or CEO is a former or current government official, NPC deputy, or CPPCC member, this is represented by 1; otherwise, signified by 0
Control variables	Enterprise size	*Size*	The natural logarithm of the total assets
	Return on equity	*ROE*	Net profit/average shareholders' equity
	Annual capital expenditure	*Capital*	The natural logarithm of the enterprise's capital expenditures
	Equity restriction	*Equ*	The sum of the shareholding ratio of the second to fifth largest shareholders/the shareholding ratio of the first largest shareholder
	The ratio of institutional shareholding	*Ihld*	The sum of the shareholding ratio of institutional shareholders among the top ten shareholders
	The ratio of independent directors	*Inder*	The proportion of independent directors to the total number of directors
	Salary incentive	*Pay*	The natural logarithm of the total annual salary of directors, supervisors, and senior executives

$$E(Patent_{it}|x_{it}) = \exp(a_0 + a_1 Sub_{it-1} + \sum a_k Control_{it} + \eta_t + \mu_i + \varepsilon_{it}) \quad (2)$$

where *Patent* denotes innovation performance; *Sub* denotes the explanatory variable of government R&D subsidy, including ex-post rewards (*Subaward*) or ex-ante grants (*Subgrant*); *Control* represents all the control variables; t represents year; i represents enterprise; η_t and μ_i represent the annual and region dummy variables, respectively; and ε_{it} is the random disturbance term, which obeys the normal distribution with zero mean and limited variance. Since the impact of R&D subsidies on enterprises' innovation, such as the knowledge spillover effect, generally has a time lag (Koski and Pajarinen 2013). Thus, ex-post rewards and ex-ante grants are set to lag for one period.

Based on the above theoretical analysis, government R&D subsidies not only directly affect the enterprises' innovation performance, but also indirectly affect the innovation performance through the mediating variable of R&D investment. Hence, to test Hypothesis 2a and 2b, we construct the mediation models by adopting the procedure proposed by Baron and Kenny (1986), and it established as follows:

$$RD_{it} = b_0 + b_1 Sub_{it-1} + \sum b_k Control_{it} + \eta_t + \mu_i + \varepsilon_{i2t} \quad (3)$$

$$E(Patent_{it}|x_{it}) = \exp(c_0 + c_1 Sub_{it-1} + c_2 RD_{it} + \sum c_k Control_{it} + \eta_t + \mu_i + \varepsilon_{i3t}) \quad (4)$$

where *RD* denotes the mediating variable of R&D investment, and the other variables are the same as above. When a_1, b_1 and c_2 are all significant, the variable R&D investment functions as a mediator. Besides, if c_1 is not significant, it will prove that R&D investment plays a fully mediating role; that is, the impact of government R&D subsidies on innovation performance is completely realized through the mediating variable of R&D investment.

To examine Hypothesis 3a and 3b, we split the enterprises in our sample according to whether they have rent-seeking and political connections. If the coefficient a_1 in Eq. (2) for the variable of R&D subsidies is positive and significant for the non-rent-seeking and non-politically connected subsamples, Hypothesis 3a and 3b are valid.

4 Results and analysis

4.1 Descriptive statistics

Table 3 presented the descriptive statistics of all variables. The results show that the mean value of innovation performance (*Patent*) is 14.494, and the standard deviation is 42.338, indicating that the number of patent applications is at a relatively high level but it has wide variations across among the different companies. The mean value of ex-ante grants (*Subgrant*) is 0.006, and it is higher than that of ex-post rewards (*Subaward*) (its mean value is 0.001), suggesting that the ex-ante grants are

Table 3 Descriptive statistics of all variables

Variables	Obs	Mean	Std. Dev.	Min	Max
Patent	1010	14.494	42.338	0	1032
Subaward	1010	0.001	0.003	3.29E − 07	0.033
Subgrant	1010	0.006	0.025	0	0.673
RD	1010	0.030	0.021	0.002	0.113
Rent	1010	0.419	0.494	0	1
Political	1010	0.321	0.467	0	1
Size	1010	21.266	0.696	19.831	23.049
ROE	1010	0.065	0.058	−0.159	0.218
Capital	1010	18.003	1.165	14.910	20.553
Equ	1010	0.905	0.665	0.030	3.386
Ihld	1010	0.208	0.189	0.000	0.749
Inder	1010	0.382	0.056	0.333	0.571
Pay	1010	15.026	0.552	13.505	16.859

the main form of government R&D subsidies. In terms of the minimum value of the two types of subsidies, all the enterprises of the sample have obtained the ex-post rewards, but some enterprises have failed to receive the ex-ante grants. The mean value of rent-seeking (*Rent*) is 0.419, which shows that the enterprises with rent-seeking behavior account for about 41.9% of the total sample. The mean value of political connections (*Political*) is 0.321, indicating that about 32.1% of the sample enterprises have political connections.

4.2 Main results

In this section, we conduct a series of empirical analyses about the impact of government R&D subsidies on enterprises' innovation performance. It includes the baseline regression, the mediating effect analysis of R&D investment, and the influence of rent-seeking and political connections.

4.2.1 Baseline regression

Table 4 reports the regressions estimated using Eq. (2). Columns (1) and (2) present the regression results of ex-post rewards on innovation performance, and Columns (3) and (4) report the regression results of ex-ante grants on innovation performance.

As can be seen from the Table 4, Column (1) suggests that ex-post rewards (L.*Subaward*) have a significant (p-value < 0.05) and positive effect on the innovation performance of enterprises. Nevertheless, these results could be biased by unobserved heterogeneity characteristics such as region characteristics that can determine the government R&D subsidies. For example, various regions maybe issue government R&D subsidies policies in different years. Hence, we control the time-invariant and region characteristics using fixed-effects regression in Column (2), and the coefficient is still positive but not significant. These results indicate

Table 4 Baseline regression

Variables	*Patent*			
	(1)	(2)	(3)	(4)
L.*Subaward*	17.872**	17.820		
	(2.25)	(1.42)		
L.*Subgrant*			8.185***	7.253***
			(2.97)	(2.62)
Size	0.248***	0.523***	0.466***	0.546***
	(4.43)	(6.24)	(6.30)	(6.53)
ROE	1.865***	2.283***	2.914***	2.532***
	(3.63)	(3.22)	(4.15)	(3.57)
Capital	0.163***	0.160***	0.125***	0.161***
	(5.08)	(3.62)	(3.03)	(3.66)
Equ	−0.145***	−0.191***	−0.225***	−0.214***
	(−3.20)	(−3.12)	(−3.75)	(−3.51)
Ihld	−0.127	−0.281	−0.445**	−0.306
	(−0.79)	(−1.29)	(−2.12)	(−1.40)
Inder	0.249	1.230	2.210***	1.480*
	(0.46)	(1.59)	(2.88)	(1.91)
Pay	0.274***	0.247***	0.327***	0.265***
	(4.33)	(2.86)	(4.19)	(3.11)
Constant	−9.864***	−15.322***	−15.432***	−16.331***
	(−8.92)	(−9.59)	(−11.62)	(−10.02)
Year fixed effect	No	Yes	No	Yes
Region fixed effect	No	Yes	No	Yes
N	1010	1010	1010	1010
Pseudo R^2	0.037	0.051	0.038	0.052

***$p \leq 0.01$, **$p \leq 0.05$, and *$p \leq 0.10$; *t*-statistics are in parentheses; L.*Subaward* and L.*Subgrant* denote that *Subaward* and *Subgrant* are set to lag for one period, the same as below

that the effect of ex-post rewards on the innovation performance of enterprises is not stable and has a weak effect. For ex-ante grants, Columns (3) and (4) show that the coefficients of ex-ante grants (L.*Subgrant*) are still positive and highly significant at the 1% level whether the time-invariant and region characteristics are controlled or not. These show that ex-ante grants have a considerable incentive effect on innovation performance. The above results support Hypothesis 1. Furthermore, for the control variables, the coefficients of enterprise size (*Size*) are significantly positive, and they show that the more significant the enterprise-scale, the more conducive to the improvement of enterprise innovation performance. The coefficients of return on equity (*ROE*) are also significantly positive, suggesting that enterprises with higher innovation performance when they have greater profitability. The results about other financial and corporate management indicators, such as annual capital expenditure (*Capital*), equity restriction (*Equ*),

Table 5 The mediating effect of R&D investment

Variables	*RD* (1)	*Patent* (2)	*RD* (3)	*Patent* (4)
L.*Subaward*	0.061	20.213		
	(0.32)	(1.23)		
L.*Subgrant*			0.057**	5.425**
			(2.33)	(2.10)
RD		17.347***		17.019***
		(8.55)		(8.34)
Constant	−0.009	−13.345***	−0.058**	−14.191***
	(−0.35)	(−8.62)	(−2.35)	(−8.93)
Control variables	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Region fixed effect	Yes	Yes	Yes	Yes
N	1010	1010	1010	1010
Adjusted R^2	0.162		0.140	
Pseudo R^2		0.062		0.062

***$p \leq 0.01$, **$p \leq 0.05$, and * $p \leq 0.10$; *t*-statistics are in parentheses

the ratio of institutional shareholding (*Ihld*), the ratio of independent directors (*Inder*), and salary incentive (*Pay*), are also in line with the expectations and the previous findings.

4.2.2 Mediating effect analysis

Table 5 reports the results of the mediating effect analysis of private R&D investment. Columns (1) and (2) present the mediating effect results for ex-post rewards, and Columns (3) and (4) show the results for ex-ante grants. We find that the coefficients are always insignificant in Columns (2) of Table 4 and Columns (1) and (2) of Table 5, suggesting that ex-post rewards have no significant impact on R&D investment and innovation performance, and there is no mediating effect. However, the coefficients of ex-ante grants in Column (4) of Table 4 and Column (3) and (4) of Table 5 are significant and positive (p-values < 5%), and the coefficient of R&D investment (*RD*) in Column (4) of Table 5 also significantly positive (p-value < 1%), these findings indicate that ex-ante grants have a significant positive impact on R&D investment. Then R&D investment plays a mediating role, thus verifying Hypothesis 2a. While the ex-ante grants effectively inspire enterprises to innovate by stimulating R&D investment, ex-post rewards can hardly motivate enterprises' R&D investment or innovation output. These results are consistent with Hypothesis 2b.

4.2.3 The influence of rent-seeking

In this subsection, we divide the enterprises into two groups (e.g., rent-seeking and non-rent-seeking) to explore whether the impact of government R&D

Table 6 The results of rent-seeking behavior

Variables	Non-rent-seeking		Rent-seeking	
	(1)	(2)	(3)	(4)
L.*Subaward*	26.384**		7.883	
	(2.45)		(0.61)	
L.*Subgrant*		8.880**		0.204
		(2.07)		(0.18)
Constant	−8.868***	−16.033***	−10.749***	−10.811***
	(−4.73)	(−7.12)	(−5.61)	(−5.58)
Control variables	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Region fixed effect	Yes	Yes	Yes	Yes
N	587	587	423	423
Pseudo R^2	0.036	0.079	0.048	0.048

***$p \leq 0.01$, **$p \leq 0.05$, and *$p \leq 0.10$; *t*-statistics are in parentheses

Table 7 The results of political connections

Variables	Non-political connections		Political connections	
	(1)	(2)	(3)	(4)
L.*Subaward*	20.255**		30.417	
	(2.05)		(1.36)	
L.*Subgrant*		6.130**		9.630
		(2.05)		(1.14)
Constant	−8.983***	−15.547***	−14.569***	−18.513***
	(−5.22)	(−7.69)	(−6.77)	(−6.26)
Control variables	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Region fixed effect	Yes	Yes	Yes	Yes
N	686	686	324	324
Pseudo R^2	0.028	0.053	0.069	0.107

***$p \leq 0.01$, **$p \leq 0.05$, and *$p \leq 0.10$; *t*-statistics are in parentheses

subsidies on innovation performance is influenced by the rent-seeking behavior. Table 6 reports the regression results in non-rent-seeking and rent-seeking enterprises. The results in Columns (1) and (2) show that in non-rent-seeking enterprises, the coefficients of ex-post rewards and ex-ante grants are both positive and pass the 5% significance test. However, for rent-seeking enterprises, as shown in Columns (3) and (4), the coefficients are positive but fail to pass the significance test at the 10% level. These findings indicate that rent-seeking behavior is a vital

factor that affects the influence of R&D subsidies on enterprises' innovation performance. Hence, it also can be said that compared with rent-seeking enterprises, the incentive effect of R&D subsidies on innovation performance is better in non-rent-seeking enterprises, which verifies Hypothesis 3a.

4.2.4 The influence of political connections

We analyze the impact of government R&D subsidies on innovation performance by dividing the enterprises into politically connected enterprises and non-politically connected enterprises, and the results are shown in Table 7. For non-politically connected enterprises, the coefficients of ex-post rewards and ex-ante grants are all significantly positive at the 5% level, as shown in Columns (1) and (2). Nevertheless, both ex-post rewards and ex-ante grants do not increase the innovation performance of politically-connected enterprises. The above results suggest that the presence of political connections may influence the impact of government R&D subsidies on innovation performance, which verifies the aforementioned Hypothesis 3b.

4.3 Endogeneity tests

The above results may be affected by endogeneity. On the one hand, the government R&D subsidies are rarely allocated randomly, and the government is more inclined to choose enterprises with high earnings and strong profitability to subsidize (Guo et al. 2016). Such enterprises, in turn, tend to have high innovative performance, which results in a reverse causality problem. On the other hand, although we control some important enterprises' characteristics in the regression model, including enterprise size, profitability, ownership structure, and so on, there are still omitted variables correlated with both R&D subsidies and innovation performance. Hence we conduct a two-stage least squares (2SlS) regression analysis to alleviate endogeneity bias.

In the 2SLS regression, the first-stage regression is conducted with two instrumental variables, including the annual industry average subsidies and annual province average subsidies (excluding the sample enterprise). The suitability of constructing instrumental variables in this way lies in that, according to China's innovation-driven development strategy, the state has different support levels for diverse industries. Also, local governments have discretion over the size of R&D subsidies (Hu et al. 2019). Thus, the implementation of R&D subsidy policies varies in different industries and different provinces. In this case, the mean values of R&D subsidies at the industry level and province level are not directly related to the enterprises' innovation performance but directly related to government R&D subsidies obtained by enterprises.

The first-stage specification of the two-stage regression setup is given as follows:

$$Sub_{it} = \theta_0 + \theta_1 Mean\_ind_{it} + \theta_2 Mean\_prov_{it} + \sum \theta_k Control_{it} + \eta_t + \mu_i + \varsigma_{it} \quad (5)$$

where *Mean_ind* and *Mean_prov* are our instrumental variables, respectively denote the annual industry average subsidies and annual province average subsidies.

The second stage regression is based on the following specification:

$$\ln Patent_{it} = \delta_0 + \delta_1 \overline{Sub}_{it-1} + \sum \delta_k Control_{it} + \eta_t + \mu_i + \phi_{it} \quad (6)$$

$$RD_{it} = \omega_0 + \omega_1 \overline{Sub}_{it-1} + \sum \omega_k Control_{it} + \eta_t + \mu_i + \phi_{i2t} \quad (7)$$

$$\ln Patent_{it} = \varphi_0 + \varphi_1 \overline{Sub}_{it-1} + \varphi_2 RD_{it} + \sum \varphi_k Control_{it} + \eta_t + \mu_i + \phi_{i3t} \quad (8)$$

where ln*Patent* is the natural logarithm of the number of invention-type patent applications, $\overline{Sub}$ is the predicted value of R&D subsidies from the Eq. (5). These models are derived, respectively, by replacing the *Sub* variable in Eq. (2)-(4) with $\overline{Sub}$.

The results of second-stage regressions that use Eq. (6)-(8) to test Hypotheses 1, 2a, and 2b are reported in Table 8. Columns (1), (3), and (4) show that the estimated coefficients of ex-post rewards all fail to pass the 10% significance test. The results in Columns (2), (5), and (6) show that the coefficients of ex-ante grants are positive and significant at the 1% level, indicating ex-ante grants are associated with more private R&D investment and innovation output in enterprises. We also perform the under-identification test and the weak-identification test to verify the validity of the instrumental variables. The Anderson LM statistics are significant at the 1% level, and the values of the Cragg-Donald Wald F statistic are greater than 10, thus confirming the validity of the IVs used. Besides, the *p*-value of the Sargan statistic fails to pass the significance test at the 10% level, indicating no overidentification problem. Overall, after considering the endogeneity, Hypotheses 1, 2a, and 2b are still confirmed.

4.4 Robustness tests

In this study, we conduct a series of robustness tests to ensure the reliability of our conclusions, including replacing the explained variable and using the Poisson model.

4.4.1 Replacing the explained variable

We replace the explained variable with the total number of patent applications (*Patent_all*) to carry out the robustness tests. The total number of patent applications includes invention patents, design patents, and utility model patents. The results are presented in Columns (1) and (2) of Table 9, and show that the coefficient of ex-post rewards is not significantly positive at the 5% level. In comparison, the coefficient of ex-ante grants is positive at a significance level of 1%. These results are consistent with the previous conclusions and indicate our findings are robust.

Table 8 The 2SLS results

Variables	ln*Patent* (1)	ln*Patent* (2)	*RD* (3)	ln*Patent* (4)	*RD* (5)	ln*Patent* (6)
L.$\overline{Subaward}$	103.700		0.966	89.850		
	(1.56)		(0.83)	(1.41)		
L.$\overline{Subgrant}$		26.119***			0.407***	20.806***
		(3.20)			(2.90)	(2.67)
RD				14.322***		12.684***
				(7.98)		(6.21)
Constant	−13.196***	−16.781***	−0.005	−13.118***	−0.059*	−16.012***
	(−8.31)	(−8.29)	(−0.19)	(−8.61)	(−1.70)	(−8.43)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Region fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
N	959	959	959	959	959	959
Centered R^2	0.202	0.011	0.175	0.266	0.0110	0.144
Anderson LM statistic (Underidentification test)	25.46***	34.70***	25.46***	25.42***	34.70***	32.87***
Cragg-Donald Wald F statistic (Weak identification test)	12.60	17.35	12.60	12.57	17.35	16.38
P-value of Sargan statistic (Overidentification test)	0.610	0.151	0.211	0.895	0.413	0.333

***$p \leq 0.01$, **$p \leq 0.05$, and *$p \leq 0.10$; *t*-statistics are in parentheses

Table 9 Replacing the explained variable and using the Poisson model

Variables	*Patent_all*		Poisson model	
	(1)	(2)	(3)	(4)
L.*Subaward*	21.158*		15.660	
	(1.85)		(1.36)	
L.*Subgrant*		1.702***		1.625***
		(2.63)		(5.45)
Constant	−12.962***	−8.380***	−18.713***	−18.888***
	(−9.16)	(−6.83)	(−4.83)	(−52.53)
Control variables	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Region fixed effect	Yes	Yes	Yes	Yes
N	1010	1010	1010	1010
Pseudo R^2	0.041	0.027	0.342	0.342

***$p \leq 0.01$, **$p \leq 0.05$, and *$p \leq 0.10$; *t*-statistics are in parentheses

4.4.2 Using the Poisson model

The selection of method may produce the bias of the estimation results, and we, therefore, use the Poisson model to conduct the robustness test. Columns (3) and (4) in Table 9 report the results of Poisson regression. The results suggest that the ex-ante grants have a positive effect on the innovation performance of the enterprise at a significant level of 1%; however, the coefficient of ex-post rewards is insignificant. Such results indicate that the incentive effect of ex-ante grants on innovation performance is better than that of ex-post rewards, and thus leading further support to the above conclusions.

4.5 Further analysis

This subsection explores the moderating effects of two specific regional characteristics on the relationship between R&D subsidies and innovation performance, including marketization and anti-corruption.

4.5.1 The moderating effect of marketization

Since the opening policy in 1978, China has transformed from a planned economy to a socialist market economy. While marketization is an important indicator to measure the transformation of a planned economy to a market economy, which reflects the role of the market in the overall operation of the social economy. Currently, the regions have obvious diversities in economic development and the degree of marketization in China. In regions with a high degree of marketization, the

Table 10 The regression results of the external influence

Variables	Moderator: *Mkt*		Moderator: *Anti_corr*	
	(1)	(2)	(3)	(4)
L.*Subaward*	86.000		17.610	
	(1.50)		(0.54)	
L.*Subgrant*		45.263***		−2.316
		(3.65)		(−1.02)
Mkt	0.019	0.042		
	(0.13)	(0.28)		
L.*Subaward***Mkt*	−7.516			
	(−1.18)			
L.*Subgrant***Mkt*		−4.612***		
		(−3.50)		
Anti_corr			0.013	0.012
			(1.12)	(1.00)
L.*Subaward***Anti_corr*			0.022	
			(0.02)	
L.*Subgrant***Anti_corr*				0.315**
				(1.99)
Constant	−10.048***	−10.555***	−9.961***	−10.233***
	(−5.69)	(−6.01)	(−7.62)	(−7.80)
Control variables	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Region fixed effect	Yes	Yes	Yes	Yes
N	1010	1010	1010	1010
Pseudo R^2	0.035	0.035	0.035	0.035

***$p \leq 0.01$, **$p \leq 0.05$, and *$p \leq 0.10$; *t*-statistics are in parentheses

government's administrative intervention on enterprises will be reduced, and enterprises can get more R&D funds from the capital market, thus reducing the effect of R&D subsidies from the government (Laincz 2009). Meanwhile, the "invisible hand" in the market will affect the distribution of government subsidies (Antonelli and Crespi 2013). Hence, we take marketization as a moderator variable to further analyze the mechanism impact of government R&D subsidies on the innovation performance of enterprises.

In this study, we employ the marketization index of China's provinces proposed by Wang et al. (2017) to indicate the degree of marketization (*Mkt*).[5] The regression results are shown in Columns (1) and (2) of Table 10. The results show that the interaction coefficient of the marketization index and ex-post rewards

[5] The larger the index (*Mkt*) is, the higher the level of marketization will be. Since the indexes for 2015 and 2016 have not been announced, this study adopts data from 2008 to 2014 to estimate the marketization index in the former two years using the exponential smoothing forecasting method.

(L.*Subaward***Mkt*) is not significant, while that of the marketization index and ex-ante grants (L.*Subgrant***Mkt*) is negative and highly significant at the 1% level. These results imply that marketization can restrain the impact of ex-ante grants on enterprises' innovation performance. That is, in regions with low degrees of marketization, the effect of ex-ante grants will be better. However, marketization has no obvious effect on ex-post rewards.

4.5.2 The moderating effect of anti-corruption

The anti-corruption policies implemented after the 18th National Congress of the Communist Party of China (NCCPC) have increased the risk cost for all corrupt people and reduced the level of corruption. It is worth noting that anti-corruption policies increase the opportunity cost of all rent-seekers, but do not change the relative situation of rent-seekers. For example, when the expected benefits of rent-seeking such as government R&D subsidies are more significant than the expected costs, enterprises still have an incentive to pursue rent-seeking through corruption (Liu et al. 2018). The existing research suggests that anti-corruption can affect enterprises' innovation performance (Dang and Yang 2016; Khyareh 2019). In regions with stronger anti-corruption, the expected costs of rent-seeking are greater than the expected benefits, and enterprises have no incentive to pursue rent-seeking through corruption (Jin et al. 2019). And thus, anti-corruption leads to a better promotion effect of R&D subsidies on enterprises' innovation. Hence, we take anti-corruption as a moderator variable to test whether this mechanism exists to affect the impact of government R&D subsidies on the innovation performance of enterprises.

In this study, we measure the degree of anti-corruption using the number of duty crimes per 10,000 public officials in each province. The number of provincial public officials is published by the National Bureau of Statistics of China,[6] and the data of duty crimes by province comes from the *Procuratorial Yearbook of China*. Columns (3) and (4) in Table 10 report the regression results. We find from the results that the interaction coefficient of anti-corruption and ex-post rewards (L.*Subaward***Anti_corr*) is insignificant, while the interaction coefficient of anti-corruption and ex-ante grants (L.*Subgrant***Anti_corr*) is significant and positive at the 5% level. These results indicate that anti-corruption strengthens the promotion of ex-ante grants to the innovation performance of enterprises.

5 Conclusion

This study aims to explore the effectiveness of government R&D subsidies (e.g., ex-ante grants and ex-post rewards) for enterprises' innovation performance using the data of China's Growth Enterprise Market (GEM) listed enterprises from 2010 to 2016. Both of these subsidies directly provide funds for the enterprises' innovative activities, but there are major differences in the distribution and actual eligibility.

[6] National Bureau of Statistics of China: http://data.stats.gov.cn

In this study, we mainly address which kind of government R&D subsidies is more effective, and how these subsidies affect enterprises' innovation performance. The main conclusions are as follows.

We first find that the various types of government R&D subsidies, including ex-ante grants and ex-post rewards, have different impacts on enterprises' innovation performance. Specifically, the ex-ante grants have a highly significant and positive effect on innovation performance, while ex-ante grants have a slight impact on it. The possible reason is that the ex-ante grants can accelerate the innovation output by stimulating private R&D investment. However, ex-post rewards only serve as a substitute for private R&D investment, thus insignificantly impact on innovation performance. Therefore, except for the existing forms of ex-ante grants and ex-post rewards, the government should explore diversified subsidies, and also increase funding for relative research institutes, to strengthen their technical support for enterprises innovative.

Second, we reveal rent-seeking and political connections in the allocation of subsidies in China. We find that enterprises obtain R&D subsidies by seeking rent from the government and establishing political connections, which is not conducive to the improvement of enterprises' innovation performance. Especially, compared with enterprises engaging in rent-seeking and political connections, the incentive effect of ex-ante grants on innovation performance is better in non-rent-seeking and non-politically connected enterprises. Hence, the government should strengthen the ability to identify those enterprises that really need R&D subsidies, so as to avoid corruptive transactions that are intrigued to diddle subsidies. Besides, the government should improve the supervision and evaluation of subsidies' implementation for targeted enterprises to improve the efficiency of using public funds.

Finally, perhaps the most interesting result of our study is that there are moderating effects of marketization and anti-corruption. Our findings suggest that ex-ante grants are more conducive to promoting innovation in areas with low degrees of marketization. Thus, with the acceleration of China's marketization, the effect of government support on R&D subsidies may be diminished. The government should build up a variety of financing platforms to accelerate the growth of R&D funds. Besides, anti-corruption has cracked down on rent-seeking and corruption in the selection of subsidy objects. Our findings show that ex-ante grants have a stronger promotion effect on innovation performance in the areas with higher degrees of anti-corruption, which demonstrates the remarkable effect of these anti-corruption measures.

We are also aware of several important limitations of our study. First, this study focuses only on Chinese listed enterprises. The results are influenced by China's transition economy, and should be compared with R&D subsidy policies implemented in other countries, especially those of developed countries. Second, the data employed allowed us to explore only two types of R&D subsidies. Further research calls for more detailed information about the typology of the received subsidies.

Appendix A: Industry distribution of the sampled enterprises

Industry description	Frequency	Percent
Chemical raw materials and chemical products	79	7.82
Medicine	93	9.21
General-purpose equipment	52	5.15
Special-purpose equipment	110	10.89
Transportation equipment	22	2.18
Electrical machinery and equipment	112	11.09
Computers, communications and other electronic equipment	164	16.24
Measuring instruments and machinery for cultural activity and office work	37	3.66
Information transmission, software and information technology	129	12.77
Others	212	20.99
Total	1010	100

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Compliance with ethical standards

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