Technovation ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Technovation

journal homepage: www.elsevier.com/locate/technovation

Do government grants promote innovation efficiency in China's high-tech industries?

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ARTICLE INFO

Article history:
Received 1 January 2015
Received in revised form
31 May 2016
Accepted 20 June 2016

Keywords:
Government grants
Industrial innovation
Private R&D
Innovation efficiency
High-tech industry

ABSTRACT

Despite extensive discussion about the important role of government in enterprise development, the function of government grants in the innovation activities of high-technology (high-tech) industries is still unclear. In this paper, the stochastic frontier model and a unique panel data set of 17 high-tech industries in China spanning the 2001–2011 period are applied to explore how government grants affect the innovation performance of these industries. Results indicate that the innovation efficiency of high-tech industries rapidly improved in the past decade. However, it is found that government grants exert a negative influence on innovation efficiency of high-tech industries. However, the impact of private R&D funding is significant and positive. Furthermore, when the high-tech industries are grouped into five sub-industries, the results show that government grants had different effects on the innovation in each sub-industry.

1. Introduction

High-tech industry is one of the most important industries in a knowledge-based economy. China's National and local governments are eager to develop the high-tech industry by investing substantial R&D grants in this sector. The objective of this paper is to investigate how government grants affect innovation efficiency in China's high-tech industry.

Chinese manufacturing industries have played a significant role in the development of China's economy since the implementation of the reform and opening-up policy. After three decade development, the Chinese government has realized that technology development and innovation are highly essential in the manufacturing industries. The government also emphasized that innovation is the driving force of economic growth and is the key factor to catch up with advanced industrial economies. These circumstances guided the Chinese government to formulate and promulgate a series of policies promoting high-technology (high-tech) industries. After years of development, China's high-tech industries accomplished considerable progress in innovation and technology development. Table 1 shows the development of China's high-tech industries from 2002 to 2011.

The economic literature on externalities indicates that innovation activities may lead to market failure (Arrow, 1962). In the national innovation system, the government plays an important role in assisting firms to enhance their competitiveness and innovation (Freeman, 1989; Lankhuizen and Woolthuis, 2004; Lundvall, 2010; Metcalfe, 1995; Nelson and Rosenberg, 1993; Patel and Pavitt, 1994; Porter, 2011; Watkins et al., 2015). However, the benefits of innovation, similar to those of public goods, are typically not completely extended to the private sector partly because innovation remains below the socially acceptable level. Consequently, governments attempt to address market failures through policy instruments, such as offering government grants. To date, many governments have already established grant-related mechanisms to promote R&D activities.

Since the 1980s, China has implemented the Torch Program for high-tech industrial development, and offered special policies and financial grants to enhance the development of high-tech industries. The Chinese government also promulgated several policies and laws to encourage enterprise R&D investment. Statistics show that the Chinese government spent approximately 60.17 billion Yuan during the past three decades to promote R&D activities. The total amount of government grants to high-tech industries has increased from 2.61 billion Yuan in 2002 to 11.59 billion Yuan in 2011, with an average annual growth rate of 34.41% (Fig. 1). Therefore, analyzing whether government grants result in positive externalities to simulate the innovation of high-tech industries in China is highly important.

This study aims to analyze the effects of government grants on the innovation of high-tech industries. According to the *China*

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http://dx.doi.org/10.1016/j.technovation.2016.06.001
0166-4972/

Please cite this article as: Hong, J., et al., Do government grants promote innovation efficiency in China's high-tech industries? Technovation (2016), http://dx.doi.org/10.1016/j.technovation.2016.06.001

Table 1
The development of high-tech industry from 2002 to 2011.

	2002	2005	2007	2009	2011
Number of enterprises (unit)	11,333	17,527	21,517	27,218	21,682
Annual average number of employed personnel (10 thousand persons)	424	663	843	958	1147
Revenue from principal business (100 million yuan)	14,614	33,922	49,714	59,567	87,527
Expenditure on R&D (100 million yuan)	187	362	545	892	1441
Patent application (piece)	5590	16,823	34,446	71,337	101,267

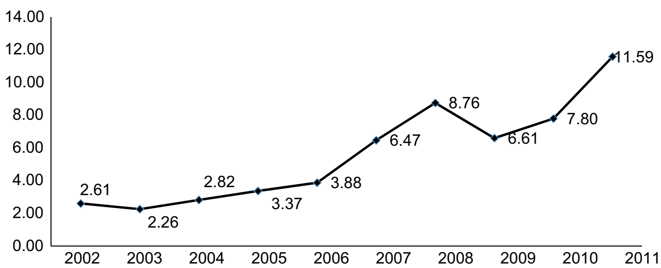

Fig. 1. The total of Government grants to high-tech industries in China from 2002 to 2011.

Statistics Yearbook on High Technology Industry, China's high-tech industrial sector is classified into five sub-sectors, namely (1) medicine, (2) aircraft and spacecraft, (3) electronic and communication equipment, (4) computer and office equipment, and (5) medical. Late on these five groups are further divided into two types of sub-industries based on R&D intensity. The reason for such division is to explore the difference in the effects of government grants on innovation. Furthermore, we investigate the effects of private R&D funding and other types of funding on industrial innovation, and estimate the innovation efficiency of high-tech industries in the past decade.

This study shows a positive effect of government grants on the innovation of high-tech industries. However, a significant difference was observed in the effect of grants on high-tech industries with different R&D intensity. To our knowledge, this issue has not been discussed in previous studies. Grants can promote the innovation efficiency in high-tech sub-industries with high R&D intensity; however, these grants can also exert a negative influence on high-tech sub-industries with low R&D intensity. Private R&D funding exerts a positive effect on the innovation of two types of high-tech sub-industries. The innovation efficiency of high-tech industries has enhanced rapidly in the past decade.

The remainder of this paper is structured as follows. Section 2 presents the literature review on government grants, private R&D funding, and industrial innovation. Section 3 describes our methodology and samples, including the variables used and data collection and processing. Section 4 discusses the results of this study. Further discussion about the implications of this study is reported in Section 5. Section 6 concludes the paper.

2. Literature review

Several studies focus on the effects of government grants on innovation. These government grants support firm innovation through various methods, such as tax preference, loans that stimulate innovation, subsidies on innovation activities, and government funding programs (Beugelsdijk and Cornet, 2002; Romijn and Albaladejo, 2002; Souitaris, 2002; Wallsten, 2000). Guan and Yam (2015) investigated the effects of Chinese government financial incentives on firms' innovation performance. These incentives include direct earmarks, special loans and tax credits. They find that special loans and tax credits affect firms' innovative performance positively while direct earmarks sometimes have negative effects. Hsu et al. (2009) investigated 127 government-funded projects in Taiwan and showed that government R&D funding alters the behavior of recipient firms and affects their innovation. Doh and Kim (2014) explored the impact of governmental support on the innovation of small and medium enterprises (SMEs) in South Korea, and the results indicate that government support had a positive relationship with industrial innovation. David et al. (2000) reviewed the literature on the relationship between R&D subsidies and R&D expenditure within different levels of aggregation. A few studies reported the effect of government subsidies on private R&D spending, financing, and innovation at the national level; however, the evidence is insufficient at the industry level. The current study measures the innovation efficiency in the Chinese context and analyzes the effect of government grants on industrial innovation. Another crucial aspect of this study is the discussion of the differences of the effects of grants on the innovation in the five sub-industries.

Several studies reported the effects of government grants on innovation; however, the findings of these studies are inconsistent because of differences in research objectives. Radas et al. (2015) investigated the effects of direct grants and tax incentives on recipient SMEs and the results suggest that direct subsidies used alone or with tax incentives strengthen the R&D orientation. Kang and Park (2012) studied the SMEs in South Korea's biotechnology industry and found that government R&D grants play a positive role in promoting innovation output; internal R&D human capital and internal R&D spending also have significant effects on innovation performance. Park (2015) analyzed the efficiency of government subsidy recipient, and found the efficiency of government subsidies among different recipients like university, laboratory and companies is different. Lichtenberg (1988) analyzed the relationship between federal contract and company R&D and concluded that government grants are not conducive to innovation output. Görg and Strobl (2007) and Wallsten (2000) investigated the relationship between government support for R&D and R&D expenditure. These researchers concluded that government grants may completely crowd out private R&D spending, and cast a negative effect on the firm's innovation. Yu (2013) revealed that the effect of government grants on innovation efficiency is insignificant from the regional perspective; these grants also have a negative effect on innovation at the regional level. By contrast, Guellec and Pottelsberghe (2003) quantified the effects of government grants on business R&D in 17 Organisation for Economic Co-operation and Development (OECD) member countries. These researchers concluded that government grants can reduce the cost of R&D activities for firms and generate further innovation by motivating additional private R&D spending. Branstetter and Sakakibara (2000) analyzed the effects of the Japanese government-sponsored research on firms by measuring the patenting performance of these firms. These researchers revealed that government sponsorship has a positive effect on innovation, which is particularly effective in basic research. Almus and Czarnitzki (2003) used a non-parametric matching approach to analyze the effects of public policy on the innovation activities of firms in eastern Germany. In comparison with firms without government subsidies, the innovation activities of government-sponsored firms increased by approximately 4%. Czarnitzki and Hussinger (2004) studied patenting performances of German firms to analyze the effects of government grants. Their conclusion shows that public R&D funding displays positive productivity effects.

Other studies discussed whether government grants will crowd

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out private R&D spending. Wallsten (2000) assessed the possible interdependence between public R&D funding and R&D expenditure of US firms via the simultaneous equation model. He concluded that government grants will crowd out private R&D spending, and that grants cast no effect on R&D activities. In contrast, Lach (2002) investigated Israeli firms and argued that government grants do not crowd out private R&D expenditure. However, such grants have a positive effect on the private R&D spending of small firms and an insignificant effect on R&D spending of large firms. Hussinger (2008) used German manufacturing firms as samples to analyze the effects of government grants on firms' R&D spending and patenting; both privately financed R&D and publicly induced R&D exhibit positive productivity effects. González and Pazó (2008) proposed a theoretical framework to study the effects of government grants on firms' decisions and concluded that firms may not be engaged in R&D activities because of the absence of grants in low-technology sectors. Herrera and Sánchez-González (2013) analyzed the additionality effects of R&D subsidies on innovation activity. Their findings show that R&D subsidies had different additionality effects on innovation process and reject the full crowding-out effects.

Previous studies mainly analyzed the effects of government grants on innovation and explored whether grants can encourage firms to increase R&D expenditure. However, the findings are inconclusive. The present study aims to determine whether government grants can increase innovation efficiency of high-tech industries in China. To explore the effect of government grants on high-tech industries, a stochastic frontier analysis (SFA) is adopted. A main feature of the current study is to classify high-tech industries into five sub-industries and analyze the effects of government grants on innovation efficiency in the different sub-industries. Sector-specific government grant policies in China are then discussed.

3. Methods, variables and data

3.1. Methods

Innovation is a knowledge production process. Most scholars use the method of SFA to measure innovation efficiency (Bai, 2013; Fu, 2012; Fu and Yang, 2009). SFA is an econometric technique which uses regression analysis to estimate a conventional cost function, with the difference being that efficiency of a Trust is measured using the residuals from the estimated equation where the error term is divided into a stochastic error term and a systematic inefficiency term (Jacobs, 2001). The method is based on a regression model which allows for statistical noise and hypothesis testing. It is superior to the non-parametric method in terms of dealing with heterogeneity and outliers (Cooper, et al. 2000; Kumbhakar and Lovell, 2003; Zabala-Iturriagagoitia, 2007). In this study, stochastic frontier production function is employed to empirically analyze the effect of efficiency factors on the innovation of high-tech industries. The stochastic frontier model was proposed by Aigner et al. (1977) and Meeusen and van den Broeck (1977). This model has been extensively used for productivity analysis in recent years (Battese and Coelli, 1995). This model can be expressed as follows:

$$Y_{it} = \alpha X_{it} + \epsilon_{it} \text{ and } \epsilon_{it} = v_{it} - u_{it} \quad (1)$$

$$v_{it} \sim N(0, \sigma_v^2),\ u_{it} \geq 0, \quad u_{it} \sim N\left(u_{it}, \sigma_u^2\right), \quad u_{it} = z_{it}\beta \quad (2)$$

where Y_{it} measures new knowledge flow in high-tech industry i (i=1, 2,…, N) in the *year* t (t=1, 2,…, T), X_{it} is the vector of input factors determining the value of knowledge production function, α and β are vectors of the unknown parameters to be estimated, and μ_{it} is the mean of inefficiency errors and is determined by a vector of efficiency factors z_{it} that may or may not be dependent on the x_{it} variables. Unlike the linear regression models, the measurement error ε_{it} in SFA consists of both a random term v_{it} and an inefficiency term u_{it}. v_{it} reflects the observation error. The inefficiency term u_{it} represents the level of inefficiency and measures the extent by which the actual output deviates from the production frontier.

To be consistent with the majority of previous studies (Hu and Mathews, 2005; Jones, 1998; Li, 2009), a log–log specification is adopted in this study, and the variables are expressed either in logarithm form or in ratio. This strategy aims to make the estimation less sensitive to outliers and allow the easy interpretation of the estimated coefficients. Moreover, innovation efficiency, defined as the technical efficiency of knowledge production, can be interpreted as the ratio of the actual innovation outputs to the potential innovation outputs. The final model is presented as follows:

$$LnY_{it} = \beta_0 + \beta_1 LnX_{1it} + \beta_2 LnZ_{2it} + v_{it} - u_{it} \quad (3)$$

$$u_{it} = \delta_0 + \delta_1 LnZ_{1it} + \delta_2 LnZ_{2it} + \delta_3 LnZ_{3it} + w_{it} \quad (4)$$

where Z_{it} is the efficiency factor of a high-tech industry. Eq. (4) is used to estimate the effect of government grants on industrial innovation in China. To analyze the influence of the principal absorption capacity of the technical inefficiency factors, the interaction terms are also employed in Eq. (4) so that optional models are estimated.

3.2. Variables

Several indicators are selected to measure the input and output of innovation. Scholars typically use R&D spending and R&D personnel to measure the inputs of innovation (Griliches, 1980; Goto and Suzuki, 1989). The current study uses intramural expenditure on R&D and full-time equivalent of R&D personnel to measure the inputs of innovation. Cruz-Cázares et al. (2013) used R&D capital stock and high-skill staff as input factors to measure technological innovation efficiency. These two indicators are the two main determinants of the new knowledge production frontier.

Previous studies discussed the employment of patents to measure innovation output (Archambault, 2002; Archibugi, 1992; Griliches, 1980). For example, Li (2011) used the number of domestic patent applications as a measure of innovation performance. Patents are widely used as a measure of innovation output. A few scholars proposed alternative indicators of innovation output. These include changes in firm-level stock market values (Pakes, 1984), number of patent citations (Trajtenberg, 1990), value of new product sales (Liu and White, 2001), literature-based innovation counts (Acs et al., 2002), and number of new products (Fritsch, 2002). Table 2 summarizes the relevant studies on the aforementioned variables.

Patent data are collected by the State Intellectual Property Office of China, and published in the *China Statistics Yearbook on High Technology Industry*. It takes several years for an invention patent application to be accepted. The number of patents granted may also be affected by the patent office's efficiency and preferences and hence may not accurately reflect the current level of innovation. For this reason, patent application numbers are used as a measure of innovation output in this study.

To address the role of government in innovation, government grants, private R&D funding, and other funding sources are employed as the efficiency factors. In particular, government grant is measured as the total amount of annual government funding obtained by a high-tech industry, whereas private R&D funding is investment in R&D activities by firms in high-tech industries. Other funding sources refer to the funds raised from other sectors, such as banks and investment institutions.

In summary, this study employs innovation output, input factors, and efficiency factors to measure innovation efficiency. Moreover, the stochastic frontier production function is estimated so that the effects of government grants, private R&D funding, and funds from other sectors on innovation output can be examined. Table 3 provides the description of the variables used in this study.

3.3. Data sources and processing

All the data used in this study are obtained from the *China Statistics Yearbook on High Technology Industry* and *China Statistical Yearbook 2003–2012*. Specifically, patent application, intramural expenditure on R&D, R&D personnel full-time equivalent, government grants, private R&D funding, and other funds are collected from the *China Statistics Yearbook on High Technology Industry*. Producer price index (PPI), consumer price index (CPI), and price indices of investment in fixed assets are drawn from the *China Statistical Yearbook*. Table 4 presents the descriptive statistics of the variables in the model.

Given the influence of price factors on R&D funding, we use CPI data Collected from the *China Statistical Yearbook 2002–2012* to convert the nominal value of R&D spending to the actual value. The base period is 1999. R&D activities have an effect on innovation in the current period as well as knowledge production in the future (Griliches, 1980). Therefore, calculating the stock of intramural expenditure on R&D is necessary. The perpetual inventory approach is adopted here:

$$K_t = E_{t-\theta} + (1-\delta)K_{t-1} \quad (5)$$

where K_t is the current R&D stock and $E_{t-\theta}$ indicates the actual R&D expenditures. It is assumed that the current intramural R&D expenditure can form the R&D capital stock after one year (Coe and Helpman, 1995; Griliches, 1980). The rate of depreciation of the R&D capital is higher than the ordinary physical capital. Following the literature, it is assumed that $\delta = 15\%$ (Pakes, 1984). Then the base period R&D capital stock can be estimated by the following formula:

$$K_0 = E_0/(g + \delta) \quad (6)$$

where K_0 is the base period R&D stock, E_0 stands for the actual R&D expenditures in the base period, and g is the average growth rate of the R&D expenditure.

4. Results

The empirical analysis of this study is conducted in two steps. First, four models are estimated so as to explore the effects of government grants. Second, the sample is divided into two subsamples and the effects of government grants on innovation are explored respectively.

4.1. Effects of government grants on the innovation of high-tech industries

The parameters of the stochastic frontier production function are estimated by using maximum likelihood method. Model 1 is the baseline model without consideration of the efficiency factors. Model 2 is estimated to examine the effects of government grants on the innovation of high-tech industries. Models 3 and 4 extend Model by incorporating the intersection terms between the intramural expenditure on R&D and full-time equivalent of R&D personnel variables and the efficiency factors. Table 5 presents the estimation results.

Table 2
Definitions and sources of the variables.

Variable name	Sources	Interpretation of indicators
1. Patent application (PA)	Bin (2008), Hussinger (2008), Guan (2010)	The total number of patent applications of enterprises per year.
2. Intramural expenditure on R&D	Bin (2008), Guan and Chen (2010), Liu and Wang (2003), Zhang et al. (2003)	Firms' annual total expenditure on internal R&D activities.
3. Full-time equivalent of R&D personnel	Zhang et al. (2003), Zhong et al. (2011)	The sum of the number of full-time R&D employees and the converted full-time equivalent of other part-time R&D personnel per year.
4. Government grants (GG)	González and Pazó (2008), Hu (2001), Hussinger (2008)	The total R&D expenditures from government grants.
5. Private funds (PF)	Chen and Yuan (2007), González and Pazó (2008), Hussinger (2008)	The R&D expenditures from the enterprises' own funds and funds entrusted by other enterprises.
6. Other funds (OF)	Chen and Yuan (2007), Hu (2001)	The R&D expenditures from bank loans, bonds and other sources.

Table 3
Variables description.

Variable	Definition	Data sources
Dependent variables		
Log *Y*	The number of patent application (in logarithm scale)	China Statistics Yearbook on High Technology Industry:2002–2011
Input factors		
Log *K*	The stock of intramural expenditure on R&D(in logarithm scale)	China Statistics Yearbook on High Technology Industry:2002–2011
Log *L*	Full-time equivalent of R&D personnel(in logarithm scale)	China Statistics Yearbook on High Technology Industry:2002–2011
Efficiency factors		
GG	Share of R&D activities funds from government grants	China Statistics Yearbook on High Technology Industry:2002–2011
PF	Share of R&D activities funds raised from firms	China Statistics Yearbook on High Technology Industry:2002–2011
OF	Share of R&D activities funds raised from other sectors	China Statistics Yearbook on High Technology Industry:2002–2011

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Table 4
Descriptive statistics of variables.

Variable	Observations	Period T	Mean	Std. Dev.	Min	Max
Dependent variables						
Log *PA*	170	2002–2011	4.5245	1.8562	0.7931	10.6175
Input factors						
Log *K*	170	2002–2011	12.1151	1.6493	8.4581	16.5114
Log *L*	170	2002–2011	8.5324	1.3254	6.8589	12.0587
Efficiency factors						
GG	170	2002–2011	9.5214	1.5472	6.2530	11.6128
PF	170	2002–2011	11.5250	1.4215	6.8564	15.0256
OF	170	2002–2011	8.8125	1.6352	5.2589	9.7652

Table 5
Estimation results of the effects of efficiency factors on the innovation of high-tech industries.

	Model 1		Model 2		Model 3		Model 4	
	Coef.	t-ratio	Coef.	t-ratio	Coef.	t-ratio	Coef.	t-ratio
Function 1								
Constant	−0.783	−0.494	2.524***	2.849	−2.438***	−2.917	−2.898***	−3.757
LnK	0.185**	1.865	0.293***	3.946	0.166***	2.189	0.265***	3.807
LnL	0.657***	5.560	0.583***	5.084	0.781***	7.442	0.662***	6.090
Function 2								
Constant			15.636***	3.562	6.725*	1.038	24.996***	2.929
LnGG			0.429**	1.839	−4.517**	−1.662	−2.652**	−2.210
LnPF			−1.768**	−1.876	−4.272*	−1.427	−0.957	−0.776
LnOF			−0.235*	−1.597	−2.567*	−1. 569	−1.562**	−1.869
LnK × *LnGG*					0.390**	1.786		
LnK × *LnPF*					−0.407**	−1.859		
LnK × *LnOF*					−0.236*	−1.578		
LnL × *LnGG*							0.361***	2.328
LnL × *LnPF*							−0.198*	−1.558
LnL × *LnOF*							−0.254**	−1.912
Sigma-squared	0.445***	4.445	1.977***	2.497	2.332***	2.895	1.753***	2.765
Gamma	0.712***	3.403	0.886***	18.214	0.884***	17.151	0.851***	14.383
Log likelihood	−154.109		−192.7		−189.402		−186.076	
LR-test	134.054***		56.873***		63.468***		70.113***	
Observations	170		170		170		170	

* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.

The estimates in all four models are above 0.7 and the significance levels are at the 1% level, indicating the validity of using production and inefficiency functions to study the effects of government grants on industrial innovation. In Model 2, the coefficients of intramural expenditure on R&D and full-time equivalent of R&D personnel are 0.293 and 0.583, respectively, and significant at the 1% level. These results suggest that the innovation elasticity of R&D personnel is greater than that of the R&D capital. Thus, talent plays a key role in industrial innovation. The coefficient of government grants is 0.429, which is significant at the 5% level, suggesting that government grants have a negative effect on the efficiency of industrial innovation. There are two possible reasons. First, government grants may have a crowding-out effect on private R&D funding, thereby reducing the efficiency of industrial innovation. Second, due to the lack of prudent monitoring and a punishment mechanism, fund-receiving enterprises may embezzle government grants for other activities, leading to the low efficiency of innovation. The coefficients of private R&D funding and other funds are −1.768 and −0.235, respectively, which are statistically significant and indicate that these funds have positive effects on industrial innovation.

We add the interactions in Models 3 and 4 to verify the moderating effects of intramural expenditure on R&D and full-time equivalent of R&D personnel on the efficiency factors and industrial innovation. Thus, the coefficient of government grants has changed from 0.429 to −4.517, −2.652, suggesting that government grants have a positive effect on innovation efficiency when moderate variables are added. The reasons for this phenomenon may depend on the following aspects. First, government grants are misappropriated. Previous studies have indicated that enterprises with government R&D grants may use government capital investment instead of their own innovation input (Görg and Strobl, 2007; Wallsten, 2000). The lack of punishing mechanism has also resulted in the tendency of funded enterprises to use government grants for other activities, thereby leading to considerably low innovation efficiency (Guan and Chen, 2010). Second, an internal incentive mechanism in high-tech enterprises is lacking. An imperfect incentive mechanism will seriously affect the enthusiasm of employees to innovate, and hence discourages efficiency in enterprise innovation. When enterprises focus on R&D, government grants are properly allocated to this activity, thereby encouraging R&D staff members and promoting innovation efficiency in the enterprises.

Table 6
Estimation results of the effects of efficiency factors on the innovation of high-tech industries.

Function	Industries				
	Medicine	**Aircraft and Spacecraft**	**Electronic and Communication Equipment**	**Computer and Office Equipment**	**Medical Equipment and Measuring Instrument**
Abbreviation	***Sub-industry I***	***Sub-industry II***	***Sub-industry III***	***Sub-industry IV***	***Sub-industry V***
Function 1					
Constant	−3.067*	−3.87***	−3.786***	−8.739***	−9.873***
	(−1.617)	(−4.622)	(−3.165)	(−8.897)	(−10.120)
LnK	0.425***	1.231***	0.415***	0.579***	1.105***
	(3.654)	(9.563)	(3.094)	(3.420)	(6.550)
LnL	0.449*	0.879***	0.492**	0.661***	0.092*
	(1.459)	(4.720)	(2.0859)	(2.721)	(1.347)
Function 2					
Constant	1.586**	37.605***	15.395**	−0.002	−0.204
	(1.634)	(1.779)	(2.277)	(−0.002)	(−0.161)
LnGG	−0.113*	−8.939**	1.142**	0.313*	0.728**
	(−1.693)	(−2.146)	(1.999)	(1.789)	(2.349)
LnPF	−0.016*	−3.229***	−2.332**	−0.203*	−0.500*
LnOF	(−1.524)	(−2.529)	(−2.206)	(−1.739)	(−1.774)
	−0.254*	−0.159*	−0.219	−0.521**	−0.671
	(−1.549)	(−1.472)	(−0.451)	(−1.897)	(−0.239)
Sigma-squared	0.257*	19.750	1.373*	0.278***	0.123***
	(1.543)	(1.048)	(1.748)	(4.050)	(2.459)
gamma	0.921**	0.998***	0.757***	0.638**	0.652**
	(1.762)	(311.652)	(4.467)	(1.696)	(1.778)
Log likelihood	−17.048	−19.846	−75.789	−22.588	−7.681
LR-test	19.80**	17.803**	22.470**	93.812***	16.924**

Note: The five sub-industries are referred to as Sub-industry I, Sub-industry II, Sub-industry III, Sub-industry IV, and Sub-industry V.
* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.

The moderating results indicate that two moderators have a negative effect on government grants and industrial innovation, and have a positive moderating effect on the other two efficiency factors and industrial innovation. These results imply that considerable intramural expenditures on R&D and full-time equivalent of R&D personnel can assist high-tech industries to absorb private R&D funding and other funds. However, these actions are not conducive to the absorption of government grants.

4.2. Further analysis of the effects of government grants on the innovation

In this section the effects of government grants on the innovation are examined in each of the five sub-industries. Table 6 shows the estimation results. The estimated coefficients of the variables imply that the intramural expenditure on R&D and full-time equivalent of R&D personnel generally shows positive effects on the innovation of the five sub-industries. Thus, innovation input may play a positive role in promoting industrial innovation. However, there are important differences in the effects of government grants on innovation in the five sub-industries. The coefficients of grants on innovation in Sub-industries I and II are −0.113 and −8.939, which are significant at the 10% and 5% levels, respectively. The coefficients of grants on innovation in Sub-industries III, IV, and V are 1.142, 0.313, and 0.728, respectively; these results are statistically significant. These results indicate that government grants have positive effects on the innovation of the medicine and aircraft and spacecraft manufacturing sub-industries but have negative effects on the innovation of the other three sub-industries.

The industrial characteristics of Sub-industries I and II necessitate the integration of multidisciplinary knowledge to develop R&D activities because innovation is time-consuming and capital-intensive. In Sub-industry I, a new drug often goes through four stages from R&D to market, namely, research (initial drug screening toxicity test), early development (clinical phase I to clinical phase II), pre-market development (clinical phase III to market access), and market tracking research stages. The development cycle approximately lasts 10-15 years. The average cost is up to 12-13 billion dollars, and the success rate of the R&D program is only 1/5000 to 1/10000. In spite of the high R&D risks in Sub-industries I and II, R&D activities are important for social development and national security. Most firms in Sub-industries I

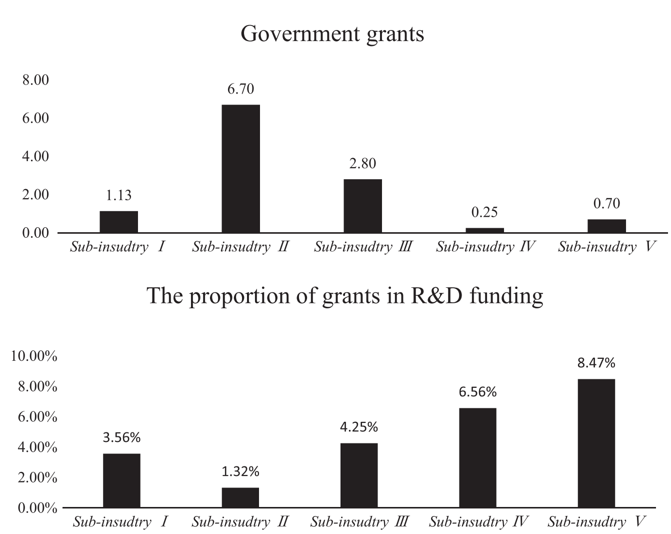

Fig. 2. The government grants and it's proportion in R&D funding in 2011.

Please cite this article as: Hong, J., et al., Do government grants promote innovation efficiency in China's high-tech industries? Technovation (2016), http://dx.doi.org/10.1016/j.technovation.2016.06.001

and II are state-owned; thus, most of the R&D funds come from government finances. Fig. 2 shows that Sub-industry II was granted 6.70 billion Yuan in 2011, which is higher than those granted to the other sub-industries. Given the huge demand for R&D funding in this type of industry, the percentage of grants in R&D funds for Sub-industries I and II was 3.56% and 1.32%, respectively, which are relatively lower than those of the other three sub-industries. The results of previous studies suggest that excessive government grants may impede innovation (Görg and Strobl, 2007; Wallsten, 2000). To explore whether grants are excessive, the percentage in R&D funding is considered. The possibility for grants to crowd out private R&D funding exists when its percentage in R&D funds is low. Government grants may supplement insufficient R&D funds in Sub-industries I and II, as well as produce crowding-out effects on Sub-industries III, IV, and V. These results suggest that government grants have a positive effect on the innovation of Sub-industries I and II but cast a negative effect on Sub-industries III, IV, and V. Thus, there are significant differences in the effects of government grants on the innovation among the five sub-industries.

The coefficients of the private R&D funding of the five sub-industries are −0.016, −3.229, −2.332, −0.203, and −0.500. These results are significant, suggesting that private R&D funding has a positive effect on the innovation in the five sub-industries. The positive effects of private R&D funding in Sub-industries II and III are greater than those of the other sub-industries, indicating that the industry innovation system has been initially established in these sub-industries. Other funds play a positive role in industrial innovation; however, the results in Sub-industries III and V are not significant.

To further study the effects of government grants on the innovation in the five sub-industries, the five sub-industries are grouped into two categories. Category I includes the medicine and aircraft and spacecraft industries. Category II includes the electronic and communication equipment, computer and office equipment, and medical equipment and measuring instrument industries. Table 7 shows the estimation results.

Table 7
Estimation results of the effects of efficiency factors on the innovation of high-tech industries.

Function	Industries			
	Category I		***Category II***	
	Coef.	**t-ratio**	**Coef.**	**t-ratio**
Function 1				
Constant	0.9734***	2.9413	0.0781	0.2046
LnK	0.8658***	23.980	0.9484***	24.448
LnL	0.0287	0.5607	0.1445	0.2576
Function 2				
Constant	4.6259*	1.7311	7.3660**	2.0146
LnGG	−1.455*	−1.7071	0.1291*	1.9156
LnPF	−0.6115*	−1.8365	−0.1409***	8.3741
LnOF	−0.4313*	−1.9769	−0.0453	−0.5283
Sigma-squared	0.6450	1.2487	0.1626**	2.5458
gamma	0.9608***	48.6830	0.7061*	1.6856
Log likelihood	12.7056		5.4079	
LR-test	75.039***		16.7139**	
Observations	90		80	

* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.

Table 7 shows the coefficients of the variables in the two categories of the five industries. In contrast with Table 6, the intramural expenditure on R&D still has positive effects on the innovation of all industries, indicating that this expenditure still plays a significant role in increasing industrial innovation. By contrast, the full-time equivalent of R&D personnel does not have a significant effect on innovation output. The coefficients of private funds on the innovation of firms in Categories I and II are −0.6115 and −0.1409, respectively, which are significant at the 10% and 1% levels, respectively. These results imply that private funds have positive effects on the innovation of all industries. Increasing all the firms' internal R&D is the most direct and effective method to promote innovation. The result of the other funds was similar to private funds. The coefficients of the other funds in Category I and Category II firms are −0.4313 and −0.0453, respectively; these funds also have a positive effect on the innovation of all industries. However, the result was significant in Category I but not in Category II.

The analysis of the preceding results further confirmed the aforementioned conclusion that the medicine and aircraft and spacecraft industries are similar to each other. Government grants in these industries can assist enterprises to reduce innovation risks and costs, as well as enhance the competitiveness of the companies. The innovation behavior and R&D activities of Category I firms tend to cost a significant amount of money and require extensive time to recover costs, thereby increasing the operational risk of these firms. However, government grants compensate for the innovation costs and failure risks. Furthermore, most of these companies are state-owned enterprises. Thus, government grants have a strong oversight role for these companies and can promote Category I firms' innovation output.

Government grants for Category II firms tend to support innovation projects with high probability of success and high return, particularly for projects that can continue without government grants. If the grantee companies use government grants instead of their own R&D funds to develop new projects and cancel projects that are not funded by the government, then government grants can produce crowding-out effects to the enterprise R&D. Moreover, government grants have increased the demand for scarce R&D resources. Then the salary level of R&D personnel will improve and the eagerness of companies to hire R&D developers is reduced. As R&D costs rapidly increase, enterprises will give up R&D projects over other profitable projects because company R&D investment is crowded out. Furthermore, the lack of government regulation was another reason for the negative effect of government grants on the innovation of Category II firms. Hence, government grants can also lead to unfair competition. In a few firms, technology is relatively outdated and should be eliminated according to market competition. However, these firms still survive with the assistance of government grants. As a result the ability of the entire industry to innovate is reduced.

4.3. Innovation efficiency of China's high-tech industries from 2002 to 2011

The China State Council issued a decision to accelerate the progress of science and technology in 1995. This decision clearly emphasized that high-tech industries should be prioritized, and special policies and funds should be offered. Government grants were provided to encourage innovation among enterprises. Many high-tech zones, such as university science parks, were built to promote industrialization. Tax relief policies and intellectual property laws were also formulated to reduce the risks related to R&D activities.

Fig. 3 presents the innovation efficiency of China's high-tech industries from 2002 to 2011 based on Model 2. The innovation efficiency of high-tech industries enhanced rapidly in the past

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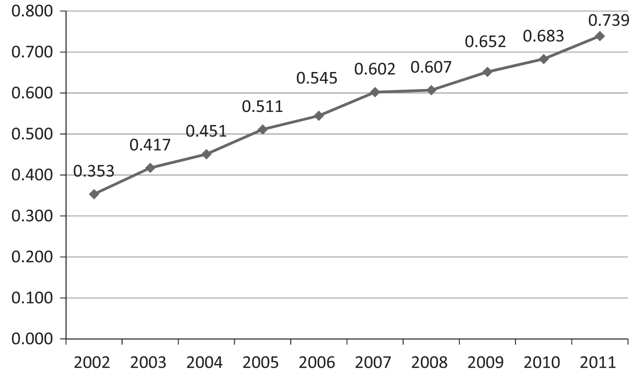

Fig. 3. The innovation efficiency of High-tech industry in China from 2002 to 2011.

decade, and the overall innovation efficiency of high-tech industries increased from 0.353 in 2001 to 0.739 in 2011. These results suggest that the innovation capability of China's high-tech industries is gradually enhancing, and government support to these industries has resulted in several achievements. However, innovation efficiency is still relatively low, and the government still needs to optimize policies to promote the innovation efficiency of high-tech industries. Additional intramural expenditure on R&D and R&D personnel can assist high-tech industries to absorb private R&D funding and other funds.

5. Discussion

Government grants, private R&D and other funds have different impacts on innovation efficiency. Our research shows that private R&D and other funds have a significant positive effect on promoting innovation, while government grants have different effects on the innovation in each sub-industry. These results confirm findings by Wallsten (2000) and Herrera and Sánchez-González (2013) that government grants partly crowd out private R&D. This study shows the mechanism of government grants promoting high-tech industry innovation and having different effects across the sub-industries.

In this study, we explored the important role of enterprises in innovation. As R&D capital and R&D personnel have a direct impact on innovation output, enterprises should increase investment in R&D, and pay more attention to research staff in order to promote innovation capability. Meanwhile, to improve innovation efficiency, the enterprises should focus on R&D capital management and R&D personnel incentives. The government should increase financial investment in medicine, aircraft and spacecraft industries, and alleviate the lack of R&D funds and the long development cycle of these industries. Furthermore, the government should strengthen the supervision and management of R&D grants, and prevent the crowding out effect of government grants.

Three policy implications can be drawn from the findings in this study. First, innovation is the driving force of enterprise development. The government should encourage enterprises to increase innovation. It can award those innovative enterprises by adjusting the tax and personnel policies. Second, due to the different effect of government grants on the innovation of high-tech industries, the government's policy should be different across the sectors. After all, medicine, aircraft and spacecraft industries are science based industries and the core strength of high-tech industries. Administrators should expect a long time lag between investment and invention, particularly in these industries. Finally, the government should encourage financial institutions to support R&D funds of the enterprise. For example, granting low-interest loans and encouraging enterprises to issue bonds can help overcome the problem of enterprise R&D capital difficulties.

6. Conclusions

This study uses data from China's high-tech industries from 2002 to 2011, and employs the stochastic frontier production function to explore the effects of government grants on industrial innovation. First, the overall effects of government grants on China's high-tech industries are investigated. Second, the effects of grants on innovation in five sub-industries are discussed. Third, the effects of private R&D and other funds on industrial innovation, and the innovation efficiency of China's high-tech industries from 2002 to 2011 are analyzed. Finally, the effects of intramural R&D expenditure and personnel on efficiency factors and industrial innovation are investigated.

The analytical results suggest that government grants have a positive effect on the innovation of the medicine and aircraft spacecraft sub-industries, and cast negative effects on the electronic and communication equipment, computer and office equipment, and medical equipment and measuring instrument sub-industries. These results may imply that the Chinese government should optimize the structure of government grant allocation, and provide additional grants to the medicine and aircraft spacecraft sub-industries.

It is found that the private R&D fund has a positive effect on the innovation of high-tech industries and other funds also cast positive effects on most sub-industries. These results suggest that the Chinese government should improve its patent protection system, establish R&D cooperation networks to reduce the costs and risks of R&D activities, and stimulate innovation incentives of high-tech firms. Diversified financial markets should also be established for high-tech firms to easily obtain funding for R&D activities.

The intramural R&D expenditure and full-time equivalent R&D personnel have positive moderating effects on industrial innovation. These results imply that additional intramural R&D expenditure and full-time equivalent R&D personnel can assist high-tech industries to absorb private R&D funding and other funds. Although we concluded that excessive government grants may provide a negative effect on industrial innovation, the proper amount of grants has not been identified or verified. Therefore, further study is required to determine the proper amount of grants.

Acknowledgments

The authors are grateful to the Humanity and Social Science foundation of Ministry of Education of China (09YJA630153) and the National Natural Science Foundation of China (71172213 and 71572188) for generous financial support. The authors also acknowledge the editors and the anonymous referees of the journal for their careful reading and constructive comments.

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