Investment and Output of Agricultural Research and Development in China

By

YAHONG HU

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Dr. Carl E. Pray

Dr. Yanhong Jin

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ABSTRACT OF THE THESIS

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YAHONG HU

Thesis Director

Dr. Carl Pray

Dr. Yanhong Jin

Technological innovation driven by research and development (R&D) is one of the major sources of long-term economic growth. The impact of R&D investment on research output or productivity is an important research topic. Public sectors had dominated agriculture research systems in China, and private sectors started playing an important role on technology innovation and productivity growth since the government policy reforms, especially the privatization of agribusiness firms. The overall goal of this thesis is to (a) better understand the relationship between public and private R&D investments in the agricultural industry of an important emerging country (China) using a random tobit model; and (b) estimate the output of R&D investments and the other contributing factors using count data analyses. Dataset used in this thesis is based upon a nationwide survey conducted among agricultural firms by Chinese Ministry of Agriculture and Center for Chinese Agricultural Policy (CCAP) in 2007.

The analysis on the relation between private and public R&D investments concludes that (a) government subsidy and privatization of agribusiness firms have a statistically significant, positive impact on private R&D investment; and (b) the impact of public R&D on applied research is positive and public R&D on development is negative on the private R&D investment, but neither is statistically significant. Furthermore, based on the count data analyses on the number of patents granted to agricultural firms, I find that (a) the patent counts is positively proportional to the amount of investment in private R&D; (b) public R&D investment on applied research has a positive effect and public R&D investment on development has a negative effect on research output; and (c) firms with their own R&D center/group have more patents granted than firms that only contract or outsource their R&D activities.

This thesis suggest several channels through which the Chinese government can increase private R&D investment as well as research output in agriculture by increasing government direct funding or positive subsidies on private research; helping firms building their own R&D center/group; strengthening the legal framework for the protection and enforcement of intellectual properties to attract domestic and especially foreign companies patenting their new technologies.

Key words: public R&D, private R&D, research output, patent counts, agriculture, China

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CHAPTER 1: INTRODUCTION

Research and development (R&D) investment is considered as a major source leading to technical change and thus, one of the driving forces of economic growth. The Frascati Manual (2002) classifies R&D into three categories: basic research, applied research, and experimental research. Basic research is the theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view (Frascati Manual 2002, p.77). Applied research is also original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective (Frascati Manual 2002, p.77). Experimental development is systematic work, drawing on knowledge gained from research and practical experience, which is directed to producing new materials, products and devices; to installing new processes, systems and services; or to improving substantially those already produced or installed (Frascati Manual 2002, p. 77). Both public sectors and private sectors invest in R&D. Public R&D refers to government and university research funded by government agencies, and provide public goods such as basic knowledge (Frascati Manual 2002, p.30). Private R&D is generally funded by the firms' own revenue, borrowed funds, other partner firms' funds, contract research funds or government subsidies (Frascati Manual 2002, p.30).

In 2000, the global spending on agricultural R&D totaled up $36.9 billion, 37.3% of which was invested by private firms. Even more so, private agricultural R&D investment accounted for 91.4% in developed countries but only 8.6% in developing countries (Pardey et al. 2006, p. 10). The share of public and private agricultural R&D investment has a striking difference between developed and developing countries. For example, in OECD countries, approximately half of R&D research on food and agriculture is invested by private sectors, and in the United States private R&D makes a significant contribution to the productivity growth of crops and livestock (Evenson and Huffman, 2006). However, in China, private R&D were limited and weak before 1990s mainly due to weak intellectual property rights, government control of agricultural input markets and limited foreign direct investment (Pray and Fuglie 2002). From the mid-1980s, Chinese government started introducing and implementing a series of public policies aiming to improve the private R&D investment. The private R&D investment business picked up a rapid increase since then. The first theme of this thesis is about the impact of public R&D investment and government policies on private R&D investment.

Previous studies investigating R&D in developing countries suggest a low level of private R&D investment but emphasize primarily the potential role of private R&D investment on productivity growth. Studies also indicate a strong positive relationship between R&D investment and agricultural research productivity, including a positive impact on economic growth (Evenson, Pray, Rosegrant, 1999; Ramaswami and Pray, 2002). The research findings on relationships between public, private R&D investments and R&D output are important to both policy makers who can initiate relative policies to stimulate economic growth, and firm's investors who demand higher productivity and returns from the R&D investment.

There are several ways to measure research output. Griliches (1984) claims that the number of patents granted to different firms reflecting technological and scientific innovations is one measure of R&D output. This is of significant practical importance since many contexts of detailed patent data are more readily accessible than R&D data (Griliches, 1984). Thus, one may use patent data as indicators of technological activity and /or output in parallel with or in lieu of R&D data. With all said, the second dimension of this thesis will investigate the impact of R&D investment on research output measured by the number of patents granted to Chinese agricultural firms.

1.1 Research objectives and methodologies

Private R&D investment is an important source of technology innovation, and productivity growth depends critically on research and development (R&D). Public sectors had dominated the agriculture research until recently, and private sectors started playing a key role in agricultural research responded to government policy reforms, especially the privatization of agribusiness firms. So the overall goal of this thesis is to better understand the relationship between public and private R&D investments in China as well as to estimate the outputs of R&D investments measured by the number of patents granted to private firms in the agricultural sectors. In particular, the following questions will be addressed: 1) do the public R&D investments stimulate or crowd out private R&D investments? 2) do the public and private R&D investments affect the number of patents granted to private agricultural research institutes and firms? And 3) what policies should the government use to encourage the development of new agricultural technology by the private firms?

1.2 Thesis structure

The thesis is organized with the following chapters. Chapter 2 introduces the background of agricultural research system and patent system in China. Chapter 3 presents a literature review, discussing the relationship between public and private R&D investment, followed with the relationship between government subsidies and private R&D investment, and ends up with the relationship between research outputs with patent counts and productivity. Chapter 4 discusses the conceptual framework that helps to model the potential relationship between public and private R&D investment, as well as the relationship between R&D investment and the number of patents granted to private companies. It also formulates hypotheses pertaining to these relationships based on the literature review and the conceptual models. Chapter 5 presents the data and chapter 6 focuses on explaining the empirical models and empirical results. Chapter 7 concludes the thesis and discusses policy suggestions.

CHAPTER 2: BACKGROUND ON CHINA AGRICULTURAL RESEARCH SYSTEM AND PATENT SYSTEM

Before the mid-1980s, public research institutes dominated the China agricultural research system while private research was negligible. Fan and Pardey (2002) summarize several research findings: 1) firms owned by public agricultural research institutes did not have independent legal status; 2) agribusiness firms owned by central and local governments were allowed to use the technologies developed by public agricultural research institutes for free or only paid nominal royalties; and 3) the public research activities were not related to their business and research staff were not well versed in either extension techniques or dealing with farmers on commercial terms because of limited time or funding.

Along with an increasing demand for agricultural research funding in the mid-1980s, 40 government decisions, regulations, and laws related to reforms of the science and technology system had been promulgated (Fan and Pardey, 2002). The main purpose of the reforms was to encourage the application of science to meet the needs of the market. The reform included Public Agricultural Research System Reforms (PARS), privatization of Chinese agricultural input markets and industry, and other policies related to tax aiming to strengthen private R&D.

The PARS evolved in two distinct phases. The first phase started from mid-1980s to early 1990s. During the first phase, the governmental research funding system shifted from institutional funding to a competitive grants system and enhanced the technology transfer from the public research system to technology end-users such as farmers. During the second phase of PARS reform starting from late 1990s, the government promoted the engagement of the public agriculture research towards more basic and basic-applied research, and encouraged commercialization of research or technologies to encourage and stimulate private research. Privatization of agricultural input markets started from late 1980s -- commercial enterprises were allowed to enter the agricultural industry of livestock, fisheries, crop and food processing, but the seed industry was the last one allowed be privatized in 2000.

In addition to the reform of PARS and agribusiness privatization, the government also undertook the following strategies to encourage more private R&D: 1) reforming the patent system by strengthening intellectual property rights (IPRs); 2) accepting applications for plant variety protection certificates; 3) offering subsidized loans for R&D; 4) eliminating business tax related to agricultural R&D; 5) allowing the deduction of revenue tax related to agricultural R&D; 6) establishing risk investment foundation for middle and small sized firms.

Through the restructuring of reforms, the private R&D in China agricultural industry experienced a significant growth since 1990s (Hu, Liang, Huang, Pray, Jin, 2011). China's R&D intensity, measured by the ratio of R&D over the total GDP, doubled in 2000 (1%) and more than tripled in 2009 (1.7%) compared with the level in the 1990s (Shi and Pray, 2010).

The reforms made some notable changes. First, the public research institutes started focusing their business activities on research-related industries, and being required to negotiate licenses or pay royalties or sign research contracts with other institutes. Second, development firms owned by public research institutes and agribusiness firms owned by governments became shareholding companies. After the reforms, gradually the firms started to lead in the agricultural R&D and many of them became publically traded companies on Chinese stock market as they expanded over time. Third, nongovernmental funding institutions including multinational firms emerged and played an important role in importing the modern agricultural technology.

China introduced the patent system in 1978 after Deng Xiaoping's open door policy and passed its first patent law in 1985. The 1985 Patent Law specified a 15-year patent protection since the date of application, but this protection was not applied to the chemical ingredient (Shi and Pray, 2010). Several amendments have been added to the first patent law to strengthen the IPRs. As a result of the US-China IP negotiation from 1989 to 1992, the State Intellectual Property Office (SIPO) amended the patent system in 1992 by increasing the duration of patent protection, incorporating the full legal protection of pharmaceuticals, and admitting chemical inventions as well as microbiological products and processes. In 2000, the SIPO brought the patent law into compliance with the trade-related aspects of IPR agreements, which gave patent owners new substantive rights to sell the patents. In 2008, the SIPO enhanced patentability standards, especially for novelty and improved design patents, and clarified patent joint-ownership rights (Huang, 2010).

Agricultural patent applications in China kept increasing during the past decade, particularly for the genetically modified (GM) crops (Gong 2010). For example, in 2002 there were 119 GM crop applications, and in 2009, the number climbed up to 342 (Liu, 2010). The China Center for Intellectual Property in Agriculture (CCIPA) reported that there were 9300 patent applications in 2008, which doubled from 4500 patent applications in 2002. According to the statistical results from China's State Intellectual Property Office (SIPO) in early 2010, almost one million patent applications across all sectors were filed in 2009, which is an 18% increase from 2008. These figures indicate an obvious fact that China has improved its capacity for protecting intellectual property rights substantially (Tian Lipu, 2010).

CHPATER 3: LITERATURE REVIEW

3.1 The Relationship between Public R&D Investment and Private R&D Investment

Science and technology plays a crucial role in economic growth and welfare improvement, especially for agricultural and rural development (Naseem, et al. 2010). Not only public R&D investment and private R&D investment are important, but also their relationship is interesting for government policy makers and private investors. In one aspect, public R&D investment can potentially complements private R&D investment because the expenditure spent by public sectors have positive external effects on private sectors through basic research, infrastructures, and knowledge accumulation (Wolde-Rufael, 2009). In another aspect, public R&D investment and private R&D investment can be substitutes. Naseem et al. (2010) argues two potential reasons for such a crowd-out relationship in developing countries. First, the public research in developing countries is more applied, which is also the nature of agricultural research. So if there is a direct competition between public and private investment sectors on applied research, the crowd-out effect will be expected between public R&D investment and private R&D investment. Second, public research overlooks the small-scale, resource-poor farmers and other vulnerable social groups who may dominate the agricultural sector in many developing countries due to marketing or institutional reasons.

David, Hall and Toole (2000) provide a comprehensive review on the relationship between public and private R&D based on the available empirical studies accumulated over the past 35 years. They show that the relationship between public and private R&D

investment are determined by public-related factors such as public R&D subsidies, public funds, government contract R&D, and other factors like technology policies which might impact the cost of R&D projects. They also pointed out that public R&D can directly and/or indirectly contribute to the private R&D because the public R&D can have a significant spillover effects on the stimulation of private R&D investment as well as the accumulation of scientific knowledge. Fuglie and Walker (2001) found similar results based on the data collected from U.S plant breeders that the public R&D did not crowd out private R&D in agricultural industry, but to some extent increased the competition on applied breeding.

By using a panel dataset of medical classes observed over 18 years and a distributed lag model, Toole (2007) finds strong empirical evidences to support positive effects of publicly supported biomedical research performed mainly at universities and nonprofit institutions on the private R&D investment in the pharmaceutical industry. Falk (2006) suggest that R&D investment at the university level is significantly positively related to private R&D that indicates a complement relationship between public and private R&D investment.

The literature on the relationship between public and private R&D offer findings under the context of different countries. Applying a matching technique to a panel data set of 2214 firms from 1990 to 1999 in Spain, Gonzalez and Pazo (2008) find that public R&D did not crowd out private R&D; neither did it stimulate private R&D. However, public support worked more effectively on small firms and low-technology sectors. Ozcelik and Taymaz (2007) find that the public R&D support programs in the Turkish manufacturing industry have a significant, positive impact on private R&D investment and the impact is more efficient among small firms. Wolde-Rufael (2009) find a long run co-integrating relationship between public and private R&D, and public R&D innovation crowd in private R&D using the Taiwan industry data from 1979 to 2007. Based on the temporal Granger causality tests, Yoo (2004) finds bidirectional causality between public and private R&D investment in the Korean based on the data of R&D expenditure from Korean Ministry of Science and Technology. Yoo (2004) claims that the Korea government should initiate a policy stimulating the public R&D expenditure that may lead to an increasing of private R&D investment, and meanwhile, the private R&D will have a positive effect on further public R&D expenditure.

The literature on the relationship between public R&D and private investment in China agricultural industry is sparse. Pray described that "more agricultural public development (Public-D) would decrease the private agricultural R&D and more agricultural public research (Public-R) would increase the private agricultural R&D investment" (Hu et al, 2011). Hu et al. (2011) find that such relationship depends on the type of public R&D investment -- the private agriculture R&D investment is positively associated with applied research, but negatively with public development research. Since Public-R supports basic research for private R&D investment; thus, it has a positive impact on reducing the cost of innovation for private firms that could enhance the willingness of private R&D investment. However, Public-D produces commercial products that compete with private sector products. And then it has a negative impact on improving the revenue of the innovations for private firms; so agricultural Public-D makes private R&D investment decreasing (Hu et al, 2011).

3.2 The Relationship between Government Subsidies and Private R&D Investment

Stimulated by the market failures pertaining to technology and innovation activities, the government sometimes provides support to industrial R&D with a hope that it will increase the efficiency and incentives of private R&D investment. However, the literature offers mixed evidence about the results. Some studies find a positive effect of government funding support on the private R&D based on the aggregate data (Lichtenerg 1986; Feldman and Kelley 2006; Diamond 1997) or the firm level data (Sakakibara 1997; Mansfield and Switzer 1985). Feldman and Kelley (2006) find that the recipients of government R&D subsidies attract additional research funding from other sources compared to firms that were not awarded government funding; and government R&D funding prefers to choose programs have higher spillover potential. Mansfield (1985) finds that federally supported R&D expenditures substituted for about three to twenty percent of private R&D investment and induced an additional twelve to twenty five percent increase in private R&D investments. Other studies evaluate the effectiveness of government R&D support programs undertaken across OECD countries; including new R&D funding program and tax incentives, on firm performance and private R&D investment (Falk, 2006).

On the other hand, other studies find a negative effect of the government subsidies on private R&D despite its original purpose is to increase private R&D investment (David, Hall, and Toole 2000; Wallsten 2000; Guellec and Potterie 2003). Using firm-level data from the Small Business Innovation Research (SBIR) program focusing on increasing private sector commercialization of innovations derived from federal research, Wallsten

(2000) finds no statistical evidence that grants increase private R&D at the firm level or firms that do more R&D receive more grant.

The impact of the government subsidies on private R&D also depends on the duration of the act. Shin (2006) finds that direct government subsidies for research in Korea have a short-lived effect on private R&D, but dropping quickly after the government funding is expired and/or removed. That is, despite a temporary positive effect, government grants did not induce recipient firms to maintain a high level of private R&D after the funded project came to an end.

3.3 The Relationship between R&D Investment and Research Output

Economic theory states that technological change and innovation is one of the major sources of productivity growth in the long run (Solow 1957; Romer 1990). Anecdotal evidences suggest that new technology (especially information technology) has substantially contributed to recent improvement in the productivity of firms. Much of technology change is the product of relatively deliberate economic investment activity, which has come to be labeled "research and development (R&D)". Agricultural research's role in boosting agricultural productivity is widely recognized (Alene, 2010). The impact of R&D investment on productivity is an important issue for the econometrics research (Balcombe et al. 2005). Using a data from 1977 to 2005 in Australia, Salim and Islam (2010) find a positive effect of R&D expenditure on economic growth -- a 0.497 elasticity of total factor productivity (TFP) to R&D expenditure. Luh, Chang and Huang (2008) analyze the growth of agricultural productivity for eight East Asian countries, and conclude that domestic R&D plays a key role of improving agricultural technology and productivity.

Using comprehensive data on all African countries from 1970 to 2004, Alene (2010) finds that technical advancement played an important role in the productivity growth, and agricultural R&D had a significant effect on productivity in African with an annual rate of return of 33%. Compared to conventional African agricultural productivity growth of 0.3%, the progress of contemporaneous and sequential technology has a higher impact reflected by an annual growth rate of 1.8% from 1970 to 2004. Furthermore, the lag impact of R&D on productivity was detected -- a 2% growth rate of R&D in 1970s led to higher productivity growth in mid 1980s. However, a decrease in R&D investment in 1980s and early 1990s caused a slower productivity growth in 2000s. Using the data from 27 countries in sub-Saharan Africa from 1971 to 2002, Block (2010) finds a positive elasticity of productivity growth rate to R&D expenditure and a 75% contribution rate of R&D to agricultural productivity assuming a ten-year lag proposed by Alene's (2010).

Using data on rice production in Philippines from 1996 to 2007, Bordey (2010) find that public R&D has led to less costly and higher productivity of rice production and contribute the positive impacts of R&D to the ability of public R&D investment in improving the technology of getting high quality seeds, adopting of hybrid and third generation modern inbred varieties. Bordey (2010) concludes that the government should pay more attention to the public R&D investment, since the research makes a 5% annually increasing rate from 1992 to 2007 of the price of rice production.

In short, a lot of studies related to relationship between R&D and research output claimed that the returns of R&D has been high (Alston et al. 2000). Chen (2008) first calculates the productivity growth in China by using a provincial-level panel data in China from 1990 to 2003, and the results suggested both that technical progress positively contributes to the increasing growth rate of productivity, and the public R&D investment is one of the important incentives for technology progress. Therefore we can see a straight relationship here -- R&D investment leads to improvement of technical progress, and thus create increasing growth rate of productivity.

The literature measure research output either by the count of patents (Griliches, 1984) or by a ratio of patents to R&D investment (Lanjouw and Schankermann, 2002). Patent is a crucial variable as an indicator of research output. De Rassenfosse (2009) claims that two dimensions impact the relationship between R&D and patent: the first one is research efforts lead to inventions, and the second one is inventions lead to patents. Inventions are most triggered by productivity effects, whereas patents are caused by the propensity to patent effect. Thus, patent counts could be considered either as an indicator of propensity to patents or an indicator of research productivity.

A lot of researchers have worked on the relationship between R&D investment and patents. Han and Lee (2007) claim that R&D investment produces patents and the more amount of R&D investment the more patents be granted. Han and Lee (2007) define a patent production function by using the number of patent granted by the U.S Patent and Trademark Office and Korean Intellectual Property Office as the output to understand the impact of R&D investment on patent, which showed an input-output relationship between R&D investment and patents. They suggest that the change in R&D investment per employee has an impact on the patents per employee in the same industry.

Jaffe (1989) defined a modified patent production based on the Cobb-Douglass model to figure out the relationship between industry R&D investment and university research on patents granted to firms. The research indicates that because of industry R&D investment inducing local R&D spending, a strong significant impact is found between R&D investment and corporate patents granted.

Kondo (1999) estimates the relationship between R&D investment and patent counts by using the patent data from Annual Report of Patent Agency from the year 1972 to 1984 in Japan and conclude with a strong positive relationship existed between R&D investment and patent application, conditioning on how strong this relationship differs from industry to industry. Additionally, in all sector of the U.S (1984) industry, the increase of industrial production leads to an enhancement of the number of patent applications and publications. Knodo(1999) believes that the R&D investment can lead to an increase of patent application both directly and indirectly through the technology stock, and the technology stock influences the patent applications.

Branstetter and Sakakibara (2002) collect data on all company-to-company cooperative R&D projects formed with a degree of government involvement from 1982 to 1992 to analyze how the Japanese government sponsored R&D impact the research productivity of firms. The author used the number of patents that a firm owned as the research output. The result shows that within the consortium, a significant positive relationship exists.

By using the patent data of OECD countries from 1981 to 2000, Prodan (2005) find a strong positive relationship between R&D investment and patent certification in the business sector. And there is also a conclusion that the R&D investments lead to patent applications with a time lag. So Prodan (2005) concludes that one of the two main ways to estimate the output of R&D investment is to use the number of patent applications to measure the innovative output. Prodan (2005) uses the R&D expenditure as the input and patent applications as the output and argues that the impact of R&D expenditures on patent applications may differ from public institutions to business sectors.

In order to determine the exact relationship, de Rassenfosse (2009) uses the number of patent counts as the dependent variable. The independent variables include number of researchers, education level of researchers, patent policy design, R&D expenditure in total and per researcher, and human capital index.

Prodan (2005), Kondo (1999), and de Rassenfosse (2009) all choose the number of patent applications to determine the R&D-Patent relationship. They consider that there is a time span between patent application and patent granted (Prodan, 2005; Kondo, 1999), for example, in Japan, it takes 2-9 years for a patent to be granted (Kondo, 1999).

Overall, R&D investments impact productivity and research output, and patent could be an effective indicator of the productivity growth and research output. The main finding in Pakes-Griliches (1984) is that not only do firms that spend more on R&D receive more patents, but also when a firm changes its R&D expenditures, parallel changes occur in its level of patenting. While this relationship is very strong in the cross-section dimension, it is weaker but still significant in the within-firm time-series dimension. The lag effects are significant but economically small. There is evidence indicate that an increase in Taiwan’s patent leads to a growth increase in the Taiwan economy, which indicated that Taiwan’s economic growth may partly result from increasing R&D investment (Wolde-Rufael, 2009).

CHAPTER4: CONCEPTUAL FRAMEWORK

This chapter aims to build the two core economic models of this thesis, R&D model and patent model, which are used to analyze the impact of public R&D investment on private R&D investment and the impact of R&D investment on research output. This chapter unfolds as follows. Sections 4.1 and 4.2 focus on the framework to model the effect of public R&D on the private R&D investment, while the former chapter describes the independent variables that included into the R&D model and the latter one introduces a random-effect Tobit model. Sections 4.3 and 4.4 focus on the framework to model the R&D-patent relationship. While the former chapter discusses the independent variables and the latter one describes four count data models that are used to test the R&D-patent relationship. Section 4.5 defines a series of hypotheses for empirical testing.

4.1 R&D model

David, Hall and Toole (2000) use the basic economic theory of firm's profit maximizing equilibrium to formulate the framework for analyzing the impact of the public R&D investment on the private R&D investment. The profit maximizing equilibrium describes that a firm can achieve a maximum profit when marginal cost (MCC) of the innovation investment, which reflects the opportunity cost of investment funds at different levels of R&D investment, equals the marginal revenue (MRR) of the innovation investment:

(4.1) $$MRR = MCC$$

When the R&D investment includes multiple projects, the profit maximizing equilibrium above can be extended by comparing the MRRi and MCCi of each project i (David, Hall and Toole, 2000). They also use the following function to describe the factors that influence MRR and MCC:

(4.2) $$MRR = f\ (R\&D\ expenditure, X)$$

(4.3) $$MCC = g\ (R\&D\ expenditure, Z)$$

Where X and Z reflect a list of variables that impact the revenue and cost of innovation investment respectively. Thus, based on the profit maximizing equilibrium 4.1 (David, Hall and Toole, 2000), the following formulas can be derived:

(4.4) $$f\ (R\&D\ expenditure, X) = g\ (R\&D\ expenditure, Z)$$

(4.5) $$R\&D\ expenditure = h\ (X, Z)$$

Basic economic theory suggests that each firm makes its goal to maximize their profits, and R&D investment is one important factor that can impact the profit by improving the expected rate of return and enhancing the expected demand for research output such as new products. As a result, a firm can be allowed to appropriate part of the profits from new research output of the R&D based innovations (Hu etc, 2011). The profit of the innovation denoted by π is the total revenue from the innovation minus the total cost of the innovation:

(4.6) $$\pi = R - C$$

Where the marginal revenue of innovation mainly consists of three parts: public and private R&D investment, sales revenue from innovations, and other factors M impact innovation benefits like technological opportunities that are possible to generate innovations, demand from potential market area. Thus, I define marginal revenue of innovations below:

(4.7) $$MRR = f\ (private\ R\&D, public\ R\&D, Sales\ revenue, M)$$

And marginal cost of innovations mainly consists of three parts: private R&D investment, public R&D investment, government subsidies for private research, and other factors N like policy changes that impact private cost of R&D projects and tax treatment which also affect the marginal cost innovation, thus I specify the marginal cost of the innovations below:

(4.8) $$MCC = f\ (Private\ R\&D, Public\ R\&D, Government\ subsidies, N)$$

Then we can derive the function below based on (4.1), (4.7) and (4.8):

(4.9)

Private R&$D\ =\ f\ (Public\ R\&D, Government\ subsidies, Sales\ revenue, M, N\ )$

By differentiating the factor Public R&D from the equation above, we got:

(4.10) $$\frac{ð\ (Private\ R\&D)}{ð\ (Public\ R\&D)} = \frac{ð\ f(public\ R\&D, government\ subsidies, sales\ revenue, M, N)}{ð\ (Public\ R\&D)}\ \gtrless 0$$

If the result of the equation is greater than zero, there is a crowd-in relationship between Public R&D investment and Private R&D investment, and if the result of the equation is smaller than zero, then a crowd-out relationship exists.

David, Hall and Toole (2000) incorporated the variables of public R&D subsidies, public funds, and government contract R&D into their model to estimate the relationship between public R&D and private R&D. They also take some cost-related factors into account, such as technology policies, macroeconomic conditions, institutional conditions which influence the capital market.

Hu et al (2011) describe that “The more agricultural public R&D investment on development, the less private agricultural R&D; and the more agricultural public R&D investment on research, the more private agricultural R&D investment.” Following Hu et al’ work (2011) I also distinct the public R&D investment on development and research activities, namely, Public-D and Public-R.

There was an agricultural industry reform in China that aimed to help the private R&D investment in the agricultural industry. So the policy changes here indicated a series of variables captured privatization and liberalization of China’s agricultural private R&D input industry.

In a short conclusion, based on the above variables included into R&D models that discussed by David, Hall and Toole (2000) and Hu et al (2011), I include the following explanatory variables,

(4.11)

$$Private\ R\&D =$$
$$f\ (public\ R, public\ D, government\ subsidies, sector\ and\ region\ dummies, policy\ changes, firm\ characters)$$

4.2 Random-effects Tobit model

The dataset we used in this thesis for the R&D model have a total of 4218 observations, and approximately one-third of the observations have a zero R&D investment. I employ a Tobit model to control for the high frequency of zero R&D investment. Given the panel nature of the dataset and the data is censored at zero on right, we use a firm random-effects Tobit model.

In a typical Tobit model we assume that private R&D investment is a latent variable y_i^*, but researchers only observe y_i such that:

(4.12)
$$y_i = \begin{cases} y_i^*, & y_i^* > 0 \\ 0, & y_i^* \leq 0 \end{cases}$$

The latent private R&D investment can be formulated below:

(4.13)
$$y_i^* = x_i\alpha + \varepsilon_i$$

Where x_i are factors that contributing to the private R&D investment and ε_i is an error term with a normal distribution of mean zero and variance σ^2,

The likelihood function of the Tobit model is:

(4.14)
$$ln(L) = \sum \{d_i(-ln\ \sigma + ln\emptyset(\frac{y_i - x_i\alpha}{\sigma})) + (1-d_i)\ ln\ (1- \emptyset(\frac{x_i\alpha}{\sigma}))\}$$

The overall likelihood is made up of two parts: the first part corresponds to the classical regression for the uncensored observations, while the second part corresponds to the relevant probabilities that an observation is censored.

4.3 Patent model

Griliches (1984) suggests that using patent counts as a dependent variable to estimate the relationship between R&D investment and research output. Griliches and Kondo (1995) built a “knowledge production function” to prove that R&D expenditure increases the number of patents granted. Based on this “knowledge production function”, Jaffe (1989) uses a state level time series patent dataset and the modified Cobb-Douglass model to test the influence of public research on patent applications by firms:

(4.15)

$$Log\ (patent\ counts) = \alpha_1 log\ (industry\ R\&D) + \alpha_2 log\ (public\ R\&D) + \alpha_3 \{log\ (public\ R\&D) * log\ (geographic\ variables)\}$$

Kondo (1999) uses four models (a linear model, a linear dynamic model, a log-linear model, a quasi-log linear dynamic model) to test the relationship between R&D investment and patent applications, and he find that the following linear dynamic model is a best one:

(4.16) $$patents = \alpha_0 + \alpha_1 * R\&D\ expenditure + \alpha_2 * technology\ stock$$

So he believes that the R&D investment can lead to an increase of patent application directly or indirectly by contributing to an increase of technology stock and then this increased technology stock influences patent applications. Technology stock T (t) can be defined as:

(4.17) $$T\ (t+1) = (1-r) * T\ (t) + TF\ (t)$$

(4.18) $$T\ (0) = TF\ (0) / (g + r)$$

(4.19) $$P\ (t) = c * T\ (t) + b * TF\ (t)$$

Where T (t) denotes technology stock at the period t, TF (t) denotes technology flow at period t, P (t) denotes patent applications at period t, r denotes an obsolescence rate of technology stock, and b, c are constants, g denotes a growth rate of TF (t).

Based on Kondo's previous results, Prodan (2005) uses three models (a linear model, a log-linear model, a power model) include patent applications as dependent variables and private R&D investment, public R&D investment as independent variables, and he find that the linear model is the best one. By comparing the coefficients of α_1 and β_1, he concludes that the number of patent applications will increase more if the government has more private R&D investment than public R&D investment.

(4.20) $$patents = \alpha_0 + \alpha_1 * public\ R\&D\ expenditure$$

(4.21) $$patents = \beta_0 + \beta_1 * private\ R\&D\ expenditure$$

Han and Lee (2007) estimate the effect of the R&D investment per employee on the patents per employee in the same industry controlling for industry and firm characteristics

(4.22) $$\frac{Patents}{labor} = \alpha_0 + \alpha_1 \frac{R\&D}{labor} + \alpha_2\ (industry\ dummy) + \alpha_3\ (firm\ characters) + \varepsilon$$

Except using the variables like number of R&D researchers, education level of R&D researchers, De Rassenfosse (2009) classifies R&D expenditure invested by a government institution and a private business sector.

(4.23)

$$ln\ (patents) = \alpha_0 + \alpha_1\ government\ R\&D\ investment + \alpha_2\ private\ business\ R\&D\ investment + \alpha_3\ Ln(patent\ policy\ design) + \alpha_4\ ln(number\ of\ R\&D\ researchers) + \alpha_5\ ln\ (number\ of\ R\&D\ researchers * education\ level\ of\ R\&D\ researchers)$$

Based on the variables used by previous literature (Jaffe, 1989; Kondo, 1999; Prodan, 2005; Han and Lee, 2007; De Rassenfosse, 2009) and the theoretical considerations, I include the following variables into the model to estimate the impact of R&D investment on patent counts.

(4.24)

Patent = f {Private R&D, public R, public D, government R&D subsidies, number of R&D employees, education level of R&D employees, sector and region dummies, firm characters}

4.4 Poisson, NB, ZIP, ZINB models

The datasets used by most of the previous studies are time-series data at the either state or country-level. However, the dataset used in this thesis only reports the number of patents granted by 2006 for each firm and, thus it is a cross sectional count data. Cameron and Trivedi (1998) indicate that the most commonly used count data models are Poisson model, Negative Binomial model (NB), Zero-inflated Poisson model (ZIP) and Zero-inflated Negative Binomial model (ZINB). Among the total 1351 observations, 923 firms indicated no patent has been granted to them and, thus, almost two-thirds of the observations have a zero count of patents. The zero-inflated model (ZIP and ZINB) is likely to fit the data better as a high frequency of zero patent count.

4.4.1 Poisson Regression Model

In a basic Poisson regression model, the number of events y_i for individual i has a Poisson distribution with a conditional mean μ depending on characteristics of individual i, (4.25) $$\mu_i(x_i) = E(y_i|\, x_i) = exp\ (x_i\alpha)$$

This function is called the exponential mean function, and the regression model specifies that y_i given x_i is Poisson distributed with density,

(4.26) $$f(y_i|\, x_i) = \frac{exp\ (-\mu_i)\mu_i\ \hat{}y_i}{y_i!}$$

The model comprising these two functions is referred to as the Poisson Regression Model,

(4.27) $$LnL\ (\alpha) = a_0 + \sum_{i=1}^{n}\{y_i\ \ x_i{}'\alpha - exp(x_i{}'\alpha) - ln\, y_i!\}$$

4.4.2 Negative Binomial Regression Model (NB)

In the Poisson Regression Model y_i has the mean $\mu_i = \exp\,(x_i\alpha)$ and variance μ_i . However, the data do not necessarily support that the equality between the variance and the mean. The Negative Binomial regression model adds an error term ε to the conditional mean of the Poisson distribution to model the unobserved heterogeneity. The mean function becomes:

(4.28) $$E\ (y_i|\, x_i) = exp\ (x_i\alpha + \varepsilon)$$

Where exp (ε) is normally assumed to follow a gamma distribution with mean one and variance α, when α equals to zero, then ZB model is the same as the Poisson model. The probability density function is:

(4.29) $$Pr(Y = y\ |\mu, \alpha) = \frac{\acute{\Gamma}\left(y_i+\frac{1}{\alpha}\right)}{y_i!\acute{\Gamma}\left(\frac{1}{\alpha}\right)}\left(\frac{1}{1+\alpha\mu_i}\right)^{\alpha-1}\left(\frac{\mu_i}{1/\alpha+\mu_i}\right)^{y_i}$$

The likelihood function for the negative binomial model is:

(4.30) $$L\ (\alpha|y, X) = \Pi Pr(y_i \mid x_i) = \Pi \frac{\Gamma\left(y_i+\frac{1}{\alpha}\right)}{y_i!\Gamma\left(\frac{1}{\alpha}\right)} \left(\frac{1}{1+\alpha\mu_i}\right)^{\alpha-1} \left(\frac{\mu_i}{1/\alpha+\mu_i}\right)^{y_i}$$

Where $E(y_i\ |x_i) = \mu_i$, and var $(y_i\ |x_i) = \mu_i(1+\mu_i)$.

By comparing with Poisson and NB models, if the null-hypothesis of α equals to zero is rejected, then NB model is better fit the dataset than Poisson Model.

4.4.3 Zero-inflated Poisson Model (ZIP)

Suppose there are excess zeros, one kind is true zeros and another kind is excess zeros. Zero-inflated models estimate two equations, one for the count model and one for the excess zeros.

(4.31) $$y_i = 0 \qquad \textit{with probability } \pi_i$$

$$y_i \sim \textit{Poisson } (\mu_i) \qquad \textit{with probability } 1\text{-}\pi_i\ (y_i=0,1,2,3\ldots)$$

Lambert (1992) introduced the Zero-inflated Poisson model, where $\mu_i = \mu(x_i, \alpha)$, and π_i is parameterized as a logistic function of the observable vector of covariances Z_i, as π_i approaches to zero, ZIP model is the same as Poisson model, thus,

(4.32) $$\pi_i = \frac{exp\ (-\ Z_i\ \mathit{\gamma})}{1+exp\ (-\ Z_i\ \mathit{\gamma})}$$

Where $E(\ y_i \mid x_i) = (1-\pi_i)\mu_i$, and var $(y_i \mid x_i) = \mu_i(1-\pi_i)(1+\mu_i)$.

4.4.4 Zero-inflated Negative Binomial Model (ZINB)

Similarly, Greene (1994), Cameron and Trivedi (1998) constructed a ZINB model:

(4.33) $$E(y_i \mid x_i) = (1-\pi_i)\mu_i$$

$$var\ (y_i \mid x_i) = \mu_i(1-\pi_i)(1+\mu_i(\pi_i+\alpha))$$

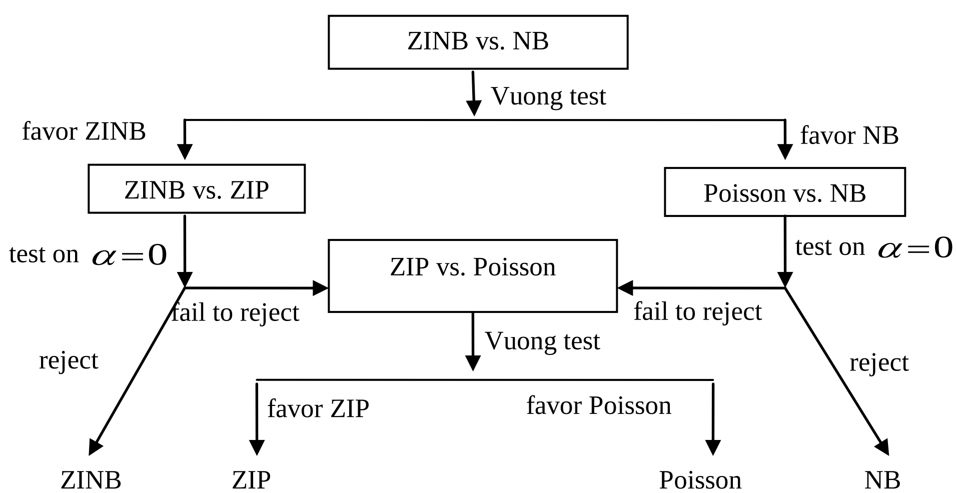
By comparing ZIP model with ZINB model, we can get that: $\frac{\pi_i}{1-\pi_i}$ and $\frac{\pi_i+\alpha}{1-\pi_i}$ indicate the degree of over-dispersion in the ZIP and ZINB models respectively.

4.4.5 Model specification

To test which model fits the data best among these four count data models, I employ both Vuong tests and likelihood ratio tests. Specifically, the Vuong test favors a zero-inflated model if Z value exceeds 1.96; and otherwise favors either Poisson or NB model if Z value is smaller than -1.96. The likelihood ratio test of the null hypothesis, Ho: $\alpha = 0$, favors NB (ZINB) over Poisson (ZIP) if the null hypothesis is rejected.

According to the Fig. 1 of model specification diagram across the ZINB, ZIP, Poisson and NB models, the following steps are used to check a best-fit model,

Figure 1 Model Specification Diagram



Step 1: Vuong test between ZINB model and NB model. Z=5.04 >1.96, and a zero-inflated model is favored.

Step 2: Alpha test between ZINB model and ZIP model. α=0.24 is very approach to zero, so ZIP model is favored.

Step 3: Vuong test between ZIP model and Poisson model. Z=9.94>1.96, so ZIP model is more favored than Poisson model.

Thus, the ZIP model fits the data best among these four count data models. In addition, we also tested the overall prediction accuracy among these four models.

4.5 Hypothesis

Han and Lee (2007) indicate that the more R&D investments, the more patents will be granted. Griliches (1994) admit that there is a positive relationship between R&D investment and patent counts. So it is reasonable to expect factors that impact R&D investment positively also have the same positive relationship with patent counts, and those factors that impact R&D investment negatively may also have negative relationship. The following hypotheses 1 to 4 are going to the R&D model and hypotheses 1-5 are going to the Patent model.

Hypothesis 1: The public R&D investment on applied research has a positive impact while public R&D investment on development has a negative impact on private R&D investment and patent counts.

Hypothesis 2: Government subsidies induce more private R&D investment and enhance research output such as patent counts.

Hypothesis 3: Privatization increases private R&D investment.

Following Hu et al. (2011) I use the number of agricultural business firms as a proxy for privatization incorporated in the model.

Hypothesis 4: Firms have own R&D centers enhance the research productivity of R&D investment.

Firms with an in-house R&D center are expected to have a greater number of patents granted than firms have no own R&D center. This may due to two reasons. First, firms with own R&D center is likely to have a greater R&D investment and, thus, increase the number of patents granted. Second, an in-house R&D center/group is potentially in a better position to gauge research capability and, thus, increasing the number of patents granted. However, it may be an empirical issue whether firms have their own R&D center/group have better research output than those have both own R&D center/group and contract R&D centers.

Hypothesis 5: The number and education level of R&D research staff have positive impacts on private agricultural research output.

CHAPTER 5: DATA

The dataset used for this thesis comes from a nationwide mail survey of agribusiness firms in 29 provinces (Hebei and Tibet are not included) in China through the Ministry of Agriculture and conducted by CCAP (Center for Chinese Agricultural Policy) in 2007. The survey collects information of the agribusiness firms' R&D investment, patent counts, government subsidies received, firm attributes, and R&D divisions in 2000, 2004, 2005 and 2005, but some variables are documented as one-time value such as respondents were asked to report the total number of patents granted by 2006. There are 503, 1059, 1236, and 1351 firms in the year of 2000, 2004, 2005 and 2006, respectively. Among 1351 firms in 2006, only 10 firms are in the machinery, pesticide, or fertilizer industry that is not oversaw by the Ministry of Agriculture and those 10 firms are not necessarily to represent these industries. Thus, I excluded these 10 firms from the analysis. The remaining 1341 firms are classified into four groups: crops, livestock, food processing, and fishery. The data set used for the private R&D model is an unbalanced panel, but the data used for the patent is a cross-sectional in which some of variables incorporated are constructed based on the panel data set. To summarize, there are 4218 firm-year observations for the private R&D model estimation and 1341 observations for the patent model estimation.

The values of R&D investment, sales revenue, and government subsidies are all deflated by consumer price index on 2006. Measured in 2006 price, private R&D investment consists of own R&D investment, contract R&D investment, and R&D investment from other firms. Table 1(a) presents summary statistics of the main variables. Private agricultural R&D investment increased from 742 million Yuan in 2000 to 1634 million

Yuan in 2006 and most of the investment was from own R&D investment. The government subsidy increased as well from 47.58 million Yuan in 2001 to 122.54 million Yuan in 2006. Firm size could be measured by sales revenue; table 1(b) shows the association between sales revenue and R&D investment, research types. I divided sales revenue by range into five groups. Compare the R&D investment between different sales revenue groups, we could get that the more sales revenue, the more firms invest on R&D research, especially on research related to food processing.

Table 1(a) Summary Statistics of Private R&D Investment, Government Subsidies, Research Staffs, and Sales Revenue

Year	Total private R&D (Thousand Yuan)	Government subsidy (Thousand Yuan)	Firm own R&D (Thousand Yuan)	Research staff	Sales (Million Yuan)
2000	742.69	47.58	688.23	10.39	71.90
2004	1068.89	98.84	999.36	11.13	102.37
2005	1259.63	114.75	1146.99	12.61	114.36
2006	1634.25	122.54	1463.03	14.04	128.66

Source: Calculated by the author based on the CCAP survey 2007

Table 1(b) Associations between sales revenue and research variables

Number of Obs	336	336	336	322	15
Sales Revenue Range (Million yuan)	0~9.08	9.08~28.06	28.06~82.82	82.82~1057.53	1057.53+
Private R&D investment(Thousand yuan)	155.99	412.93	866.8	2911.53	18930.65
Public R(Million yuan)	383.16	382.92	382.94	382.76	382.46
Public D(Million yuan)	1765.15	1764.12	1763.75	1758.64	1761.33
Crops	0.39	0.31	0.25	0.13	0
Livestock	0.23	0.23	0.22	0.32	0.26
Fishery	0.03	0.07	0.07	0.07	0.2
Food Processing	0.35	0.39	0.46	0.48	0.53

Source: Calculated by the author based on the CCAP survey 2007

In Table 2, all data is divided into two parts to compare the R&D investment, firm attributes, R&D division and other related factors between firms have patent and do not have patent. Firms with patents granted have higher sales revenue, private agricultural R&D investment, government subsidies, and research staff than firms that do not have patents. Table 2 also shows that, by comparing all these variables over time, private agricultural R&D investment, government subsidies, sales revenue, and number of research staff has an increasing trend.

To gain a better understand of patents granted to agricultural firms in China, I classify patents into product, process and package & marketing patents (see Figure 2(a)), or into agriculture, food, packaging, and others patents (see Figure 2(b)).

Table 2 Comparison of Key Variables between Firms with patents and not

Number of Observations	No patent	With patent
	923	428
Average patent count	0	2.61
Sales revenue (Million Yuan)	85.22	162.89
Private R&D investment (Million Yuan)	730.29	2366.20
Government Subsidies for private research (Million Yuan)	57.60	201.72
Research Staff without a PhD degree	6.97	23.54
Research Staff with PhD degree	0.14	0.45
Public R (Million yuan)	75.58	88.31
Public D (Million yuan)	300.26	349.34

Source: Calculated by the author based on the CCAP survey 2007

Figure 2(a) Percentage of Firms Holding Different Types of Patents by Sector

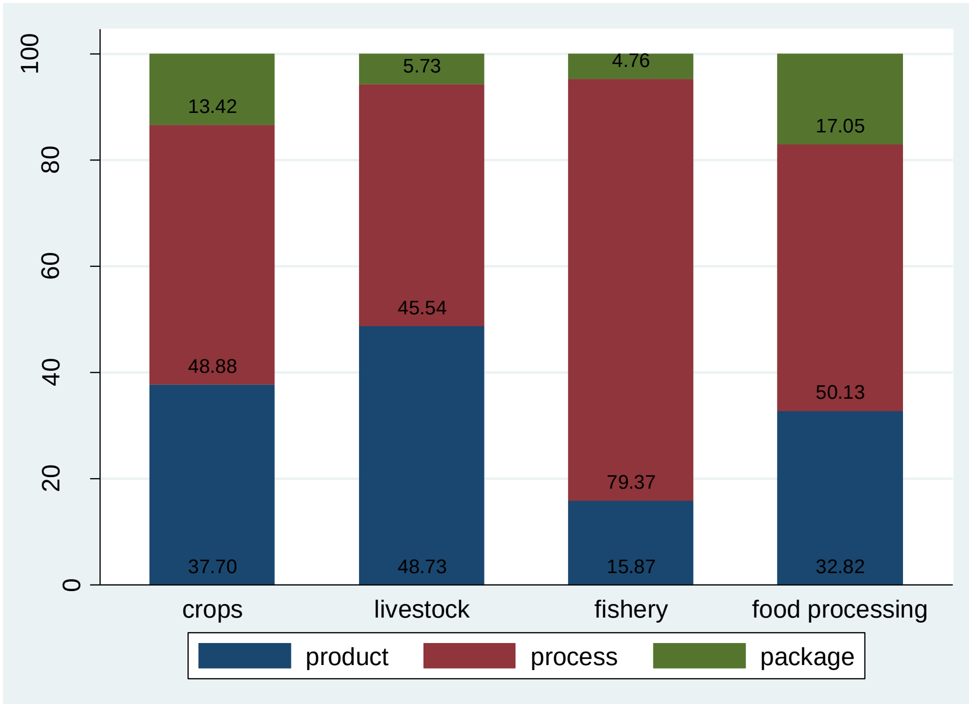


Figure 2(b) Percentage of Firms Holding Different Types of Patents by Sector

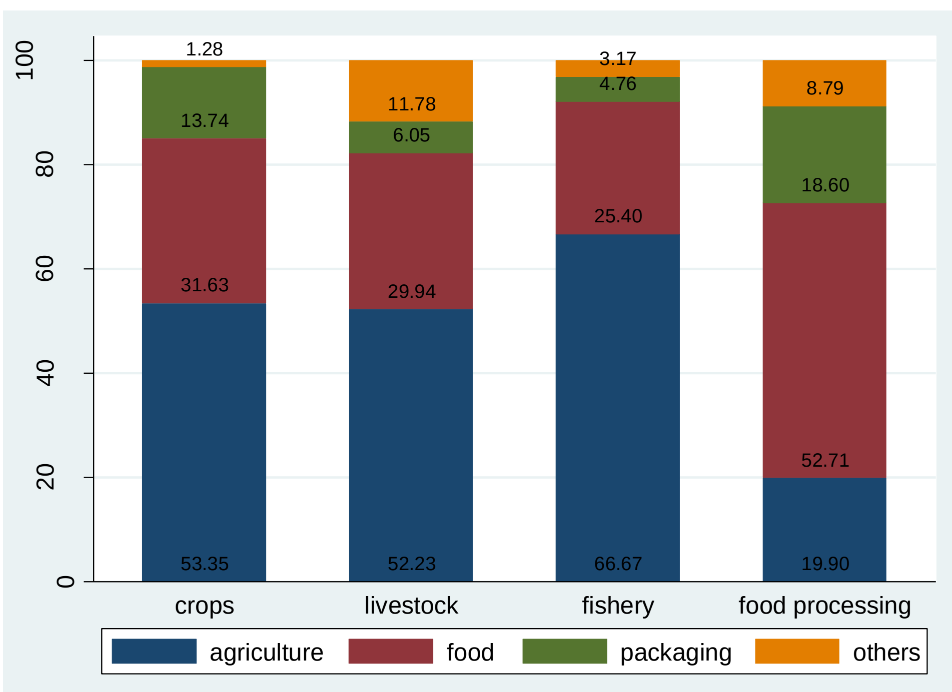


Table 3 shows the detail information of patent data. The first row shows that almost two thirds of all firms have no patent reported. Among those firms have patents, there are 157 firms have only one patent and 54 firm have more than 6 patents. The second row of Table 3 shows that firms in the food-processing sector have more patents than other sectors. As shown in Figure 3, firms with R&D investment have more patent counts than firms without R&D investment.

Table 3 List of the Number of Firms by Patents Classifications

No. of patents	No. of firms		% of firms
0	927		68.41
1	157		11.59
2	104		7.68
3	58		4.28
4	36		2.66
5	19		1.40
6+	54		3.99
	1355		100
Patent type	No. of firms	No. of patents	% of patents
Product	208	421	38.20
Process	261	552	50.09
Packaging & Marketing	66	129	11.71
Total		1102	100
Patent type	No. of firms	No. of patents	% of patents
Agriculture	216	467	42.38
Food	219	418	37.93
Packaging	70	137	12.43
Others	43	80	7.26
Total		1102	100

Figure 3 Shares of Firms with Different Number of Patents Count Among those with and without Private R&D Investment

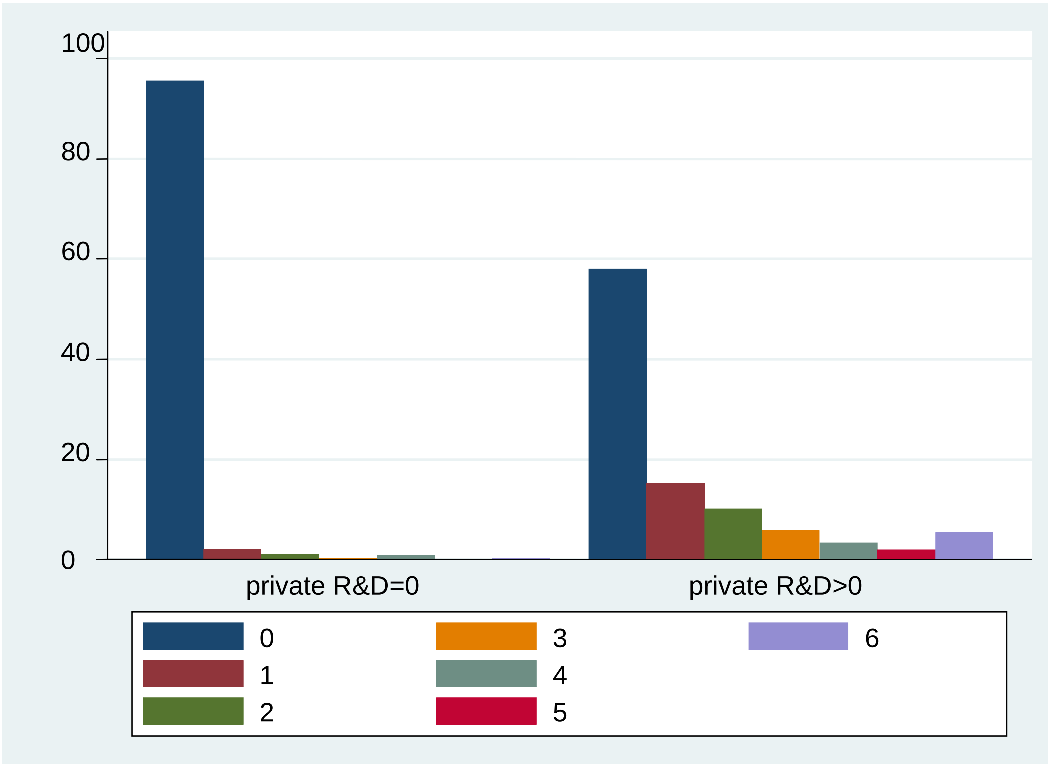


Table 4 shows the summary statistics result of the variables used in the regression models. From this result, we could expect that, sales revenue and government subsidies have positive impact on private agricultural R&D investment, and private R&D investment, government subsidies, sales revenue, and the number of research staff have positive impacts on patent counts of firms. Sector dummies, ownership dummies, R&D division dummies, and province dummies are also incorporated.

Table 4 Summary Statistics of Key Variables

Variable	2000	2004	2005	2006
No. of observations	497	1052	1228	1341
Total Private R&D investment (Million yuan)	0.74 (2.71)	1.06 (3.61)	1.25 (3.89)	1.61 (4.59)
Patent number (count data)	0.96 (1.66)	0.88 (1.58)	0.82 (1.53)	0.80 (1.52)
Public-R (Million yuan)	45.73 (67.44)	59.10 (77.49)	74.07 (92.36)	83.14 (103.96)
Public-D (Million yuan)	110.17 (170.41)	257.09 (340.48)	299.96 (386.70)	335.43 (430.62)
Government subsidy (Million yuan)	0.048 (0.358)	0.099 (0.722)	0.114 (0.780)	0.123 (0.601)
Sale revenues (Million yuan)	72.45 (238.64)	102.74 (427.28)	114.20 (499.59)	128.14 (594.85)
Firm age (years)	7.53 (8.86)	7.20 (7.37)	7.33 (7.16)	7.79 (7.08)
Non PhD R&D Staff	8.00 (41.19)	7.96 (48.84)	8.60 (50.76)	9.11 (50.00)
PhD R&D Staff	0.13 (0.69)	0.18 (0.84)	0.24 (1.04)	0.34 (1.31)
Listed firms (dummies)	0.02 (0.15)	0.02 (0.14)	0.02 (0.13)	0.02 (0.13)
Ownership (dummies)				
Private	0.61 (0.49)	0.70 (0.46)	0.72 (0.45)	0.73 (0.44)
State	0.16 (0.37)	0.11 (0.31)	0.09 (0.29)	0.09 (0.29)
Foreign	0.002 (0.04)	0.009 (0.03)	0.002 (0.049)	0.002 (0.05)
Other	0.09 (0.51)	0.06 (0.43)	0.06 (0.42)	0.06 (0.42)
Collectively-owned	0.13 (0.33)	0.12 (0.32)	0.11 (0.31)	0.11 (0.31)
Sector (dummies)				
Crops	0.25 (0.44)	0.26 (0.44)	0.27 (0.45)	0.27 (0.44)
Livestock	0.25 (0.44)	0.24 (0.43)	0.24 (0.43)	0.25 (0.43)
Fishery	0.07 (0.25)	0.07 (0.25)	0.07 (0.25)	0.06 (0.24)
Food Processing	0.42 (0.50)	0.43 (0.50)	0.43 (0.50)	0.42 (0.49)
R&D division (dummies)				
In House R&D	0.54 (0.50)	0.52 (0.50)	0.50 (0.50)	0.50 (0.50)
Contract R&D	0.06 (0.24)	0.08 (0.26)	0.07 (0.27)	0.08 (0.27)
Both in-house and contract R&D	0.14 (0.34)	0.14 (0.34)	0.14 (0.34)	0.13 (0.34)
No R&D	0.26 (0.44)	0.27 (0.44)	0.28 (0.45)	0.29 (0.45)

CHAPTER 6: EMPIRICAL RESULTS

6.1 Specific empirical models used in this thesis

Based on the conceptual framework in Chapter 4, the background of private R&D in China, and how the private R&D investment and other factors, the following empirical models are formulated for the private R&D investment model:

(6.1)

Private R&D = α_0 + α_1Public-R + α_2 Public-D + α_3Subsidies + α_4Sales + α_5Sales^2 + α_6 Firm age + α7 Number of Agribusiness firms + α_8 Ownership dummies + α_9 Province/Region dummies + α10 RD division dummies + λ_i + μ_{it}

Where E (X_{kit} λ_i) = 0 for all k, t and i.

Public-R and Public-D can potentially affect patent counts through two channels. First, public R&D investment can either crowd in or crowd out private R&D investment and, thus affecting the research output. Second, public R&D may affect research output by the spill-over effect from the public sector to the private sector. I first estimate the private R&D investment using the public R&D investment in both development and research as explanatory variables:

(6.2) Private R&D = r_0 + r_1 Public-R + r_2 Public-D + δ

And I then use the residual from equation (6.2) in the patent equation for private R&D investment along with other variables:

(6.3)

Patent count = $\beta_0 + \beta_1\delta + \beta_2$Public-R + β_3Public-D + β_4Subsidies + β_5Sale + β_6Research staff + β_7PhD Research staff + β_8 Firm age + β_9 Ownership Dummies + β_{10}Region Dummies + β11 R&D division Dummies + r_{it}

Thus, the estimated coefficient, β_1, reflects the effect of the private R&D investment on research output; and β_2 and β_3 captures the effect of public R&D investment on research output. Furthermore, I use three year average (2004, 2005, and 2006) of public R and public-D by province and sector for the patent equation.

Similarly, government direct funding of the firm's R&D is the three year average at the firm level. There are four types of R&D division in agricultural firms. Some firms have own R&D research center/group; others do not have own R&D research center/group, but they contract other firms' R&D resources; others have both own R&D and contract R&D centers; and the remaining do not have any format of R&D center/group at all. The human capital of R&D activities measured by total number of research staff without a PhD degree and total number of research staff that hold a PhD degree are also incorporated in the patent model.

Other firm attributes include sales revenue, firm age, and ownership and province dummies. The ownership includes state-owned firms, collectively owned firm, private firms, foreign-owned firms, others.

Table 5 shows the definitions and measurement units of the explanatory variables.

Table 5 Definitions and Measurement Units of the Explanatory Variables

Variable	Definition and Unit
Private R&D	R&D from own firms, contract firms, and others; unit=Million Yuan (RMB)
Patent counts	Granted patents by firm
Public R	Public research; unit= Million Yuan (RMB)
Public D	Public development; unit= Million Yuan (RMB)
Government subsidy	Government direct funding; unit= Million Yuan (RMB)
Sale revenues	Sale revenues by year; unit= Million Yuan (RMB)
Firm age	The number of years since the firm has been established
Non PhD R&D staff	The number of R&D employees without a PhD. Degree
PhD R&D staff	The number of R&D employees with PhD. Degrees
Listed firms	1=the firm is listed on a Chinese stock market; 0=otherwise
No. of Agr-firms	Year 2000=503; Year 2004=1059; Year 2005=1236; Year 2006= 1351
Ownership	Dummy variables
State-owned	
Private	
Foreign	
Other	
Collectively-owned	
Sectors	Dummy variables
Crops	
Livestock	
Fishery	
Food processing	
R&D division	Dummy variables
Own R&D only	1=the firm only have own R&D center; 0=otherwise
Contract R&D only	1=the firm only have contracted R&D center; 0=otherwise
Both R&D	1=the firm only have both own and contracted R&D centers; 0=otherwise
No R&D	1=the firm only have no R&D center; 0=otherwise
Region	Dummy variables
East	1=the firm is located at east part of China; 0=otherwise
Central	1=the firm is located at central part of China; 0=otherwise
West	1=the firm is located at west part of China; 0=otherwise

Using STATA software package, the data from 1341 firms in 2000, 2004, 2005 and 2006 were used to estimate the impact of public R&D on private R&D. Four patent models, Poisson, Zip, NB and ZINB, are estimated to estimate the impact of R&D investment on research output, which is indicated by patent counts. The estimation results of the R&D model are reported in Table 6. The estimation results of the patent model are reported in Table 7.1 and the marginal effects can be found in Table 7.2.

6.2 Empirical results of the R&D models

Table 6 shows two regression results. The first column lists the regression results of R&D models using province dummies, and the second column shows the R&D models using region dummies. Both regressions have similar results, except a few differences on values of coefficients. The findings are summarized below.

1) Public R&D investment in applied research has a positive impact, but public R&D investment in development has a negative impact on private R&D investment. However, the impacts are not statistically significant. The results partly support Hypothesis 1.
2) The government subsidies have a statistically significant, positive impact on private R&D investment, the same result as the previous literature proved (Mansfield and Switzer, 1985; Lichtenerg, 1986; Diamond, 1997; Sakakibara, 1997; Falk, 2006; Feldman and Kelley, 2006), which supports Hypothesis 2. However, we need to be warned that even if the original purpose of government funding is to increase the private R&D investment, the results are different depending on how this funding works.

3) The number of agricultural business firms has a statistically significant, positive impact on private R&D investment, which indicates that the privatization of China's agricultural sector has a positive impact on increasing the private R&D. This empirical result testify hypothesis 3.

4) Both sales revenue and firm age have statistically significant, positive impacts on private R&D investment. Firm size can be measured by sales revenue, so larger size firms invest more than small size firms. The firm age may indicate the firms' experiences, the more experiences, the more chances or higher abilities to invest money on R&D. All firms included into the dataset are classified into the type of ownership. The regression results show that there are significant differences across different firm ownerships. Choosing state firms as a base, government owned firms invest least in R&D and collectively-owned firms invest more than the other four kinds of ownership firms.

5) Firms with their own R&D center/group are associated with greater private R&D investment than their counterparts. The reason might be that firms have own R&D center/group have more incentive than those with both own and contracted R&D centers to keep the inventions safe. This result supports Hypothesis4.

Table 6 Empirical Results of R&D Models

Variable	Model 1	Model 2
Public-R (Million yuan)	0.912	0.39
	(14.33)	(15.08)
Public-D (Million yuan)	-0.974	-0.33
	(2.89)	(3.04)
Government subsidy (Million yuan)	0.773***	0.784***
	(0.09)	(0.09)
Sale revenues (Million yuan)	6.735***	6.819***
	(0.25)	(0.26)
Sales squared	-0.0004***	-0.0004***
	(0.00002)	(0.00002)
Firm age (years)	30.15***	27.515***
	(9.75)	(10.10)
Number of agricultural firms	1.896***	1.888***
	(0.40)	(0.42)
Publicly traded firms (1/0)	5577***	5312***
	(481.91)	(484.78)
Ownership (base=State-owned)		
Private	1335***	1084***
	(257.75)	(257.57)
Foreign participation	-34.94	-539.96
	(1233.98)	(1287.58)
Collectively-owned	2253***	2172***
	(307.18)	(314.66)
Other	1429***	950***
	(345.45)	(348.12)
Sector (base=Crops)		
Livestock	-214.41	344.641
	(870.63)	(1029.19)
Fishery	-447.11	331.063
	(1087.08)	(1200.64)
Food Processing	-1046.78	-160.717
	(1172.25)	(1299.03)
R&D division (base=Own R&D)		
Contract R&D	-998.49***	-1041***
	(230.03)	(239.74)
Both R&D	-86.03	-98.401
	(176.29)	(181.93)
No R&D	-40904	-41638
	(511162)	(384018)
Region (base=Central)		
East		167.09
		(175.33)
West		421.94**
		(198.46)
AIC	52345.31	52570.61
BIC	52648.82	52709.71

Note: The asterisk, *, **, and *** indicates 10%, 5% and 1% significance level, respectively; Model 1 uses province dummies, but the estimation results are not reported for the province dummies; Model 2 uses region dummies.

6.3 Empirical results of the patent models

Based on the above model specification in section 4.4.5 and the in-sample prediction results showed in Table 7.1, we found that ZIP model is a best-fit empirical model to estimate research output measured by patent counts. I summarize the estimation results based on Table 7.1 and Table 7.2 below:

1) Private R&D investments have a statistically significant, positive impact on patent counts. The finding is also consistent with the previous research (Griliches, 1984; Jaffe, 1989; Kondo, 1999; Han and Lee, 2007; De Rassenfosse, 2009).
2) Public R&D investment on applied research has a positive impact while public R&D investment on development has a negative effect as we expected, but these variables are not statistically significant.
3) Government subsidy for private research has a positive impact on research output but is not statistically significant. This result support hypothesis 2.
4) Foreign firms are granted significantly less patents than state-owned firms in China. There might be two reasons for this result. First, most of foreign firms cooperated with private firms or state-owned firms in China, and thus this type of firms are classified into joint ownership firms. From our dataset, among 1341 firms there are only 2% foreign firms. Second, Foreign-owned firms patent less new technologies because they have little faith in the patent system rather than low research output.
5) . Firms located in the east and west regions have more patents than firms in the central region, and firms in the east China have the most patent counts than firms in other two regions.

6) Firms with their own R&D centers have more patents granted than firms that contract R&D with other organizations or do not have R&D centers. Firms that patent their new technologies are more inclined to do in house R&D, since within house R&D they can keep their new technologies secret until they patent them. Firms with both own R&D centers and contract R&D centers do the most R&D investment. This result support Hypothesis 4.
7) The impacts of the number and education level of research staff on patent counts are positive and significant as the previous literature shows (Han and Lee, 2007), and the number of Ph.D research staff has more significant impact, which supports hypothesis 5.

In conclusion, the empirical results of these patent models are interesting. Firstly, there is a strong positive relationship between private R&D investments and patents granted. The number of research staff, especially how many PhD research staff has a positively significant impact on patent counts granted. Firms with both own R&D centers and contract R&D centers owned the most patents, and followed by firms with own R&D centers; Firms only have contract R&D centers or do not have R&D centers own less patent counts. In addition, firms of foreign have fewer patents than state firms. Firms located in east region and west region have more patent counts than the other region. Table 8(a) and Table 8(b) show that the patent types of process or others received the most government subsidy and produced the most sales revenue; however, the number of patent types of process and others are only 11.71% and 7.41%. This might be a reason why several key explainable variables such as public R&D, government subsidy, sales, and firm age is non-significant.

Table 7.1 Estimation Results of the Four Count Data Model

Variable	Poisson	NB	ZIP	ZIP Inflated	ZINB	ZINB Inflated
Private R&D investment[a] (Million yuan)	0.044***	0.049***	0.020**	-0.062	0.017	-0.084
	(0.008)	(0.013)	(0.013)	(0.053)	(0.024)	(0.160)
Public-R (Million yuan)	0.001	0.008	-0.016	-0.031	-0.018	-0.039
	(0.023)	(0.019)	(0.035)	(0.037)	(0.045)	(0.055)
Public-D (Million yuan)	0.006	-0.002	0.004	0.007	0.004	0.009
	(0.006)	(0.004)	(0.008)	(0.009)	(0.011)	(0.013)
Government subsidy (Million yuan)	0.058***	0.035	0.027	-0.051	0.034	0.002**
	(0.005)	(0.009)	(0.038)	(0.205)	(0.069)	(0.388)
Sale revenues (Million yuan)	-0.053	-0.083	-0.013	0.0001	0.016	0.0002
	(0.066)	(0.148)	(0.067)	(0.0002)	(0.104)	(0.0005)
Firm age (years)	0.003	0.005	-0.002	-0.007	-0.003	-0.008
	(0.008)	(0.010)	(0.004)	(0.010)	(0.004)	(0.012)
Non PhD R&D Staff	0.0003***	0.001***	0.0003	-0.008***	0.0004	-0.011**
	(0.000)	(0.001)	(0.000)	(0.003)	(0.001)	(0.004)
PhD R&D Staff	0.024***	0.043***	0.002	-0.076	0.001	-0.096
	(0.006)	(0.013)	(0.051)	(0.089)	(0.057)	(0.145)
Publically traded firms	-0.558	-0.709	-0.158	1.275	-0.076	1.505
	(0.467)	(0.630)	(0.284)	(1.320)	(0.314)	(1.493)
Ownership (base=State owned)						
Private	-0.204	-0.153	-0.350**	-0.263	-0.429**	-0.406*
	(0.296)	(0.168)	(0.150)	(0.315)	(0.206)	(0.243)
Foreign participation	-1.173	-0.773	-2.081***	-3.339	-1.949**	-2.887
	(1.325)	(1.546)	(0.763)	(4.941)	(0.954)	(2.139)
Collectively-owned	0.020	0.022	-0.175**	-0.371	-0.244**	-0.488
	(0.187)	(0.167)	(0.072)	(0.316)	(0.113)	(0.297)
Other	-0.006	0.195	-0.013	-0.253	-0.008	-0.283
	(0.215)	(0.267)	(0.232)	(0.169)	(0.268)	(0.231)
Sector (base=Crops)						
Livestock	0.283	0.211	0.483	0.328	0.543	0.454
	(0.618)	(0.359)	(0.915)	(0.988)	(1.007)	(1.121)
Fishery	-0.055	-0.055	-0.415	-0.608	-0.442	-0.713
	(0.254)	(0.266)	(0.321)	(0.744)	(0.300)	(0.946)
Food Processing	0.170	0.226	0.020	-0.318	0.022	-0.363
	(0.273)	(0.196)	(0.257)	(0.603)	(0.256)	(0.809)
R&D division (base=Own R&D)						
Contract R&D	-1.197***	-1.150***	-1.018***	0.179	-1.049***	0.103
	(0.301)	(0.3331)	(0.213)	(0.720)	(0.231)	(0.836)
Both R&D	0.245	0.297**	-0.053	-0.645***	-0.059	1.499*
	(0.160)	(0.126)	(0.108)	(0.199)	(0.142)	(0.462)
No R&D	-1.868***	-1.829***	-0.690***	1.558***	-0.779**	-0.406***
	(0.051)	(0.049)	(0.240)	(0.291)	(0.35)	(0.243)
Region (base=Central)						
East	0.280***	0.278***	0.151***	-0.223	0.196***	-0.186***
	(0.024)	(0.038)	(0.027)	(0.050)	(0.027)	(0.055)
West	0.129***	0.158***	-0.185***	-0.614	-0.177***	-0.690***
	(0.017)	(0.040)	(0.027)	(0.028)	(0.029)	(0.156)
Vuong test			Z=9.94		Z=5.04	
Alpha test		α=1.97			α=0.24	
Overall prediction accuracy	41.71%	42.08%	43.08%		42.30%	

Note: The asterisk, *, **, and *** indicates 10%, 5% and 1% significance level, respectively.

Table 7.2 Marginal Effects based on the Four Count Data Models

Variable	Poisson	NB	ZIP	ZINB
Private R&D investment[a] (Million yuan)	0.024***	0.027***	0.036***	0.042
	(0.004)	(0.007)	(0.014)	(0.043)
Public-R (Million yuan)	0.001	0.005	0.003	0.003
	(0.013)	(0.010)	(0.014)	(0.013)
Public-D (Million yuan)	0.0009	-0.001	-0.0004	-0.004
	(0.003)	(0.002)	(0.004)	(0.003)
Government subsidy (Million yuan)	0.032***	0.019***	0.036	0.020
	(0.003)	(0.015)	(0.057)	(0.099)
Sale revenues (Million yuan)	-0.0009	-0.0009	-0.0007	-0.0008
	(0.0007)	(0.0001)	(0.0006)	(0.0001)
Firm age (years)	0.002	0.003	0.002	0.001
	(0.004)	(0.005)	(0.006)	(0.006)
Non PhD R&D Staff	0.0002***	0.001	0.003**	0.004**
	(0.0001)	(0.001)	(0.001)	(0.002)
PhD R&D Staff	0.013***	0.023***	0.031***	0.036*
	(0.003)	(0.007)	(0.008)	(0.019)
Publically traded firms	-0.236	-0.279	-0.418**	-0.438**
	(0.151)	(0.175)	(0.189)	(0.207)
Ownership (base=State-owned)				
Private	-0.117	-0.086	-0.110	-0.115
	(0.181)	(0.099)	(0.240)	(0.236)
Foreign participation	-0.379	-0.293	-0.400**	-0.415*
	(0.233)	(0.393)	(0.191)	(0.234)
Collectively-owned	0.011	0.012	0.033	0.015
	(0.104)	(0.092)	(0.159)	(0.147)
Other	-0.003	0.115	0.112	0.112
	(0.117)	(0.173)	(0.133)	(0.143)
Sector (base=Crops)				
Livestock	0.167	0.121	0.170	0.171
	(0.394)	(0.218)	(0.446)	(0.418)
Fishery	-0.029	-0.029	-0.034	-0.043
	(0.132)	(0.137)	(0.140)	(0.110)
Food Processing	0.094	0.125	0.139	0.148
	(0.156)	(0.112)	(0.152)	(0.163)
R&D division (base=Own R&D)				
Contract R&D	-0.418***	-0.405***	-0.448***	-0.451***
	(0.058)	(0.068)	(0.074)	(0.061)
Both R&D	0.147	0.180**	0.225*	0.248
	(0.107)	(0.087)	(0.133)	(0.160)
No R&D	-0.792***	-0.772***	-0.805***	-0.811***
	(0.006)	(0.009)	(0.006)	(0.027)
Region (base=Central)				
East	0.156***	0.154***	0.182***	0.193***
	(0.012)	(0.023)	(0.017)	(0.009)
West	0.073***	0.089***	0.122***	0.133***
	(0.009)	(0.022)	(0.019)	(0.004)

Table 8(a) Comparison of Key Variables by Patent Type

Variable	Product		Process		Package	
	With patent	Without patent	With patent	Without patent	With patent	Without patent
Number of observations	1140	205	1090	255	1279	66
Patent counts	0	1.99	0	2.12	0	1.95
Public Research	382.88	383.23	382.89	383.13	382.96	382.50
Public Development	1762.56	1765.01	1762.84	1763.38	1763.02	1761.47
Private R&D	1023.73	2531.29	972.22	2455.70	1066.54	4877.44
Government subsidy	66.20	320.73	91.84	161.34	98.65	228.36
Sales revenue	91.47	211.90	99.37	154.55	103.91	224.67
Non-PhD research staff	9.44	24.46	10.20	18.30	9.96	46.03
PhDs research staff	0.22	0.48	0.19	0.56	0.25	0.46
Firm age	7.57	8.95	7.76	7.89	7.72	9.02

Table 8(b) Comparison of Key Variables by Patent Type

Variable	Agriculture		Food		Package		Others	
	With patent	Without patent	With patent	Without patent	With patent	Without patent	With patent	Without patent
Number of observations	1134	211	1129	216	1261	84	1303	42
Patent counts	0	2.13	0	1.92	0	1	0	1.81
Public Research	382.89	383.23	382.89	383.18	382.95	382.80	382.93	383.34
Public Development	1762.61	1764.18	1763.07	1762.25	1763.04	1761.38	1763.08	1758.60
Private R&D	1058.78	2300.21	1026.72	2438.91	1210.11	1907.22	1193.31	3125.17
Government subsidy	70.81	288.76	94.63	159.28	99.60	186.39	92.84	482.74
Sales revenue	101.44	154.92	98.06	171.33	105.23	179.03	100.32	404.84
Non-PhD research staff	9.45	24.01	10.60	17.64	10.77	26.14	10.52	49.37
PhDs research staff	0.19	0.64	0.25	0.34	0.26	0.32	0.24	1.04
Firm age	7.59	8.80	7.89	7.24	7.62	10.23	7.71	9.98

CHAPTER7: CONCLUSIONS

Public sectors had dominated the agriculture research in China, and private sectors started making an important role on technology innovation and productivity growth until recently after the policy reforms. Using survey data on 1341 firms across 29 provinces across the year of 2000, 2004, 2005 and 2006 in China, this study analyzes the impact of public R&D on private R&D investment, and quantifies the impact of private R&D on the output of R&D as measured by patent counts. Several key findings are as followings.

7.1 The impact of public R&D investment and private R&D investment

The Chinese government policy of privatization of agribusiness has a positive role on the improvement of private R&D investments. Private agricultural R&D investment has increased fast from 742 million yuan in 2000 to 1,634 million yuan in 2006. The number and size of agribusiness firms have rapidly increased, which indicates that private sector firms have more opportunities to invest in agriculture R&D. This finding is similar to previous work of Hu et al (2011).

The empirical results also showed that government R&D subsidies increase the private agricultural R&D investments. So if the government wants to encourage the increase of private R&D investment, it can increase the amount of subsidy funding. However, it is crucial to control how these funding are invested to make sure the government meets its original goals.

In addition, this thesis finds another interesting result related to firm ownership. All 1341 firms are classified by ownership: state firms, private firms, foreign firms, other firms, and joint ownership firms. We find that joint ownership firms invest the most on R&D. Other firms and private firms invest more than state firms too.

Many other government policies have been implemented to enhance the private R&D investment in China. As part of the future work, we will add more data information to this dataset and estimate the impact of these newly adopted policies on private R&D investment.

7.2 The impact of R&D investment on research output measured by patent counts

Private R&D investments have positive role on increasing the research output. Firms that invest more on private R&D are granted with more patents. Our results regarding impact of private R&D on patent counts is consistent with most previous research work. So if the Chinese government aims to enhance research output, one way to do so is to encourage the increase of private R&D investments. However, one interesting finding in this thesis shows that foreign firms invest more on private agriculture R&D, but have fewer patents than the state firms. One reason may be that the multi-national firms prefer applying for patents outside of China where more adequate intellectual property laws are enforced.

Another key finding is that firms with their own R&D centers patent more than firms with only contract R&D centers. Firms that are inclined to patent the new technologies prefer in-house R&D, which provides better protection of the intellectual properties before the patents are granted.

In conclusion, the government could encourage private agricultural R&D investment by increasing government direct funding or positive subsidies; in order to improve the number of patents granted for private enterprises. In addition, the government could help the firms build their own R&D centers. The government may also needs to strengthen the legal framework for the protection and enforcement of intellectual properties to attract domestic and especially international firms patent their new technologies.

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