EKONOMIHÖGSKOLAN

22 August 2012

R&D Efficiency and Ownership: Evidence from the Biotechnology Sector in China

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Contents

Abstract

In the west, out-innovating China has been a frequent proposal to deal with the feared threat posed by China's rapid industrialization. However, China is not content with being only a manufacturing economy and has subsequently introduced multiple programs to foster research and development domestically. One of the most prominent sectors targeted by China's programs and upheld by the west as their opportunity to shine is the biotechnology sector. But western biotechnology firms do not stay completely in the west; they have in recent years established research centres and development facilities in many Chinese cities. This enables a comparative analysis of the R&D efficiency between foreign firms and domestic firms, as well as joint ventures and state-owned enterprises. Institutional theory suggests that industry such as biotechnology where innovation works parallel with development should benefit from lower government involvement. This hypothesis is tested through a non-parametric data envelopment analysis for the different ownership types present in China. Using both constant returns to scale (CRS) and variable returns to scale (VRS); foreign enterprises, private firms and firms with investments from Hong Kong and Taiwan were found to be technically efficient under both CRS and VRS. State-owned enterprises were found to be less scale efficient while exhibiting increasing returns to scale.

Keywords: Data envelopment analysis, Biotechnology, R&D efficiency, China, Ownership

I. Introduction

China has since casting off its Soviet legacy in research and development (R&D) policy placed a heavy focus on biotechnology. The reasons are plentiful; food supply security, increasing crop yields, increasing the income for farmers, ensuring water quality as the country keeps industrializing, controlling epidemics such as SARS and developing new drugs and treatments for an aging population (Huang & Wang, 2003). Biotechnology has also been pushed by Chinese officials as an area in which China could catch-up to western developed nations and in the last few five-year plans, increasing R&D expenditure as a percentage of GDP has been a constant target with the latest five-year plan which spans over 2010-2015 puts the target at 2.2 percent of GDP to be reached by 2015. Another target states that there should be 3.3 patents for every 10,000 people (Casey & Koleski, 2011).

This push by China has not gone unnoticed in the historically leading countries in biotechnology. In the 2011 state of the Union speech the president of the United States declared that, for the US to compete with China and the world in the coming years they would have to out-innovate the world (The White House, 2011). Similar rhetoric can be heard from the European Union, which in its 2020 document outlines the need for an innovation union in order to stay competitive. The EU 2020 strategy for an innovation union contains a number of policy proposals including shared metrics and statistics for innovation companies across the union and further harmonisation of patent laws and regulation (European Commission, 2010).

These international developments have opened up discussion on the optimal ownership structure for efficient research and development. China has uniquely had its biotechnology research industry grow almost exclusively from public investment and research programs, establishing public research institutes and biotechnology firms. By large, the developed world uses the public sector, mainly universities, for basic research on genetics and other subjects while the private sector is responsible for turning the basic research into products such as new drugs, fertilizer etc. The private sector in developed countries is also expected to conduct some basic research on their own (Chen, Lou, Zhang, & Yaguang, 2011).

Regarding ownership structure, many researchers have noticed that there is a link between innovation performance and ownership (e.g., Berliner, 1976; Graves, 1988; Baysinger, Kosnik, & Turk, 1991; Dilling-Hansen, Madsen, & Smith, 2003) few have developed theories on how ownership structure affects the performance of R&D efforts. A paper by Chen *et al* (2012) suggests the merging of corporate governance theory, internalization theory and resource dependance theory and argue that this accounts for the valuable resources provided by the different ownership types (state, local non-state, and foreign), their resources would lower the enviromental uncertainty faced by the firm and thereby enable a higher rate of product development. Their research suggest that a diversified ownership structure would produce the best results. However, institutional theory developed by Huang & Xu (1998) and Qian & Xu (1998) focuses on the different budget constraints faced by different firms and identified different research sectors where hard or soft budget constraints would be more beneficial. Firms owned by the state, or with state guaranteed funding would do better in space technology but worse in computer technology or biotechnology. The difference depends on whether or not the basic science needed for the research projects already is available. In this paper, data from the latest yearbook of high-technology (National Bureau of Statistics, 2010) is used to test the hypothesis posed by theoretical work developed by Huang & Xu (1998) and Qian & Xu (1998) that firms with soft budget constraints, represented by state-owned firms, are less efficient than private firms in the field of biotechnology. As this theory deals specifically with biotechnology rather than general innovation, it is a better fit.

The hypothesis will be tested using data envelopment analysis (DEA) for the technical and scale efficiency of the different ownership structures. Data envelopment analysis involves the use of linear programming to construct a non-parametric frontier over the data. This enables the calculation of the efficiencies relative to this frontier. A major benefit of this method is that there is no need to specify the production function with its assumptions; therefore the method is widely used to calculate R&D efficiency (Coelli, 1996). For example; the efficiency of R&D in China has been examined on a regional level by Zhong *et al* (2011); they used the First Official China Economic Census Data in 2004 to examine the R&D efficiency of the provinces and aggregate regions. With data envelopment analysis they examined the impact of expenditure and personnel for R&D purposes on the patent applications filed, sales revenue of new products and the profits of the primary business. The difference between the regions was quite substantial with only a few provinces being efficient while the vast majority was operating below full technical efficiency.

The research theory of soft-budget constraints is not testable in its most stringent interpretation. Such a test would require data on projects started, project duration, project cancellation, funding details for each project undertaken etc. Instead, input and output variables are examined for the inefficiency and wasted resources that would occur should project decisions made by state-owned enterprises be less efficient as theory suggests. In addition, the data breakdown on industry and registration status used only exists in the latest 2010 edition of the High-technology yearbook and that rules out panel data Malmquist-index creation to measure the changes in R&D efficiency over time and prevents the use of a time-lag between input variables and the output in the form of invention patent applications. Also, the high-technology yearbooks up until 2009 only include medium and large sized firms. As shown by the OECD report, the Bioeconomy to 2030: Designing a Policy Agenda (OECD, 2009), small firms constitute an ever larger part of biotechnology R&D. Furthermore, as data envelopment analysis does not require the specification of the production function for innovation, something that is understandably difficult to specify, it also cannot be tested for model goodness-of-fit in a comparable way to econometric methods.

Findings point towards confirming the theory on soft budget constrain by Huang & Xu (1998) and Qian & Xu (1998) as state-owned enterprises are less efficient in producing invention patent applications. The results show that all ownership forms exhibit full technical efficiency under variable returns to scale and that all forms except state-owned enterprises lie on the production frontier with constant returns to scale. As they lie on the production frontier they are also scale efficient. However, state-owned enterprises have an efficiency score of 0.571 in the constant returns to scale model which if taken without the variable returns to scale, would indicate that inputs could be reduced by 42.9 % and still produce the same output. To achieve scale efficiency in state-owned enterprises, the R&D personnel could be reduced by 42.9 percent, intramural expenditure reduced by 14.9 %, equipment expenditure reduced by 62.6 %, external expenditure reduced by 42.3 % and government funds by 82.3 % in order to reach scale efficiency.

The remainder of the paper in structured as follows: Section II introduces the theoretical framework regarding R&D; Section III presents the history and state of biotechnology research in China with subheadings for the reforms enacted concerning biotechnology, the agricultural biotechnology and the life science part of biotechnology research; Section IV presents the data and describes the model used for testing and the DEA methodology; Section V; presents the results and sensitivity analysis with discussion and interpretation; Section VI offers conclusions and suggestions. Following is a bibliography.

II. Theoretical Framework

In literature, discussion on innovation and R&D dates back to Schumpeter (1950) with his assertion that innovation is of fundamental importance to the evolution and survival of economic organisations. He further argues that people are unable to anticipate the impact of successful innovations even after their technical feasibility has been established. Ultimately, as R&D cannot be predicted, it cannot be easily optimized. However, there are things we can learn from different historical patterns. For example, there are strong indications that state ownership of a firm can stifle R&D and innovation. Argued by Berliner (1976), when he examined the innovation decisions in Soviet industry and their incentives that the Soviet industry suffered from a lack of incentives for innovators as the inventors could not reap the reward for their work. Such rewards would only be possible under a market system rather than a society committed to state owned firms. The study sets out to examine the structural factors that impacted the spread of innovation in the post-war Soviet economy. These factors are assumed to be prices, decision rules, incentives and organizational relations between the different enterprises.

However, Berliner's study (1976) has received some critique. The first one is that the scope of Berliner's book is very limited; it is only concerned with civilian industry and even within the civilian sector it only applies to how already existing firms choose to research and develop new products. Also, the aim of Berliner's work was to look at the structural properties and separate it from the policies that come from a command style economy. But to accomplish that aim there is a need for a model to describe to important factors and their influence. Arguably this task could be extremely difficult or even impossible as a command economy, compared to a market economy, as the central planners often change and modify the structure itself. But as no attempt at constructing a model is presented as Berliner insists on remaining at the firm level and not taking the Soviet planners into the argument (Granick, 1977).

Early work on the conditions for innovation in market economies where undertaken by Kendrick (1961) who examined cross-sectional differences in growth of total factor productivity. Kendrick analysed a limited amount of manufacturing companies in the United States and focused on the relationship between total factor productivity and R&D expenditure. This work was further built upon by Mansfield (1968); he also used a relatively small sample of manufacturing firms but analysed them with the use of an explicit production function in which accumulated and depreciated R&D expenditure was treated as a form of capital. A number of different specifications were modelled and tested and, like Kendricks study, he found a significant effect for R&D expenditure on the firm's rate of technological achievements.

For market economies, macro models also started to include research and development. Incorporated into the neo-classical endogenous growth models and theories by Solow (1957), Lucas (1988), and Romer (1990), was the impact of technological change. At another level, Nelson (1982) realised the importance of R&D on technological change, and researched the interaction of knowledge and R&D efficiency. R&D was defined as a search with associated costs and a search that could be pursued to varying degrees with stochastic outcomes, knowledge was conceptualised as the capacity to focus this search in an efficient way. Nelson suggested that in industries with rapid technological progress, firms develop the necessary scientific theories for their activity and share this knowledge with the public. Griliches (1979) used data on 833 manufactures in the US on the years 1957-1965 to measure the elasticity of R&D for each industry and found significant differences. A later follow up study by Griliches & Mairesse (1984) showed, in addition to estimating the elasticity of R&D, a significant positive relationship between productivity and R&D.

Research theory developed by Huang & Xu (1998) and Qian & Xu (1998) suggests that more command driven firms and countries should be less efficient in biotechnology research. Their theory indicates that firms with soft budget constraints, as are present in government supported firms, are more efficient in research areas where the basic science is well understood. This is contrasted by firm with hard budget constraints, predominantly firms operating in a market setting. The soft budget constraint, as coined by Kornai (1986), means that firms have very large reserves of funding or implicit guarantees of such funding from the state. The hard budget constraint is the opposite; firms have limited funds for their research projects and no guarantees of funds in the case of need. These guarantees can be explicit or implicit.

According to the theory by Huang & Xu (1998) and Qian & Xu (1998), the difference between firms with a soft budget constraint and a firm with a hard budget constraint lies in different incentives for decision making in the R&D process. Soft budget constraints will impede a firm's willingness and ability to cancel projects once they have been started. This leads to squandered resources as projects continue even after they have been discovered to be unfruitful. But this is also known to the firms with a soft budget constraint therefore they will rely more heavily on pre-project screening to determine the viability of research endeavours. Screening which costs resources and takes up time, making the firm's R&D slower and less responsive. Firms with hard budget constraints however, will not face the same incentive structures. Instead, they are prone to start more projects quickly and cancel them if results do not materialize. But there is also a difference in the type of research endeavours to be undertaken. Soft budget constraints are theorized to be helpful in R&D where the underlying basic science is already developed, giving a lower chance of project failure. As an example the authors present the case of the Soviet Union and the United States: the Soviet Union was able to keep pace or even lead in space technology but unable to keep up with the United States in the development of computers. For space technology, the physics behind rocketry and aerodynamics were already well known while the solid state technology necessary for computers had to be researched at the same time for the development of physical computers. Biotechnology is claimed to be in the same category as computers.

> *Hypothesis: In the field of biotechnology research and development, state-owned enterprises are less efficient compared to privately owned firms.*

III.Biotechnology R&D in China

In the years of pre-reform China, the R&D as well as S&T policies of China were modelled after the Soviet Union with comprehensive and specialised universities supported by a network of research institutes (URIs). Almost all research was conducted by public research institutes under strict central control by the government and the focus was on large projects for heavy industry and defence. Even though many enterprises had their own S&T organisations and institutes, the capacity for in-house R&D was small. After the initiation of reforms in 1978, the Chinese government has gradually moved away from the Soviet style technology innovation towards new policies that would give incentives to all participants in R&D: the enterprises, the universities and the research institutes (Zhong & Yong, 2007). A major factor for the lack of interest in biotechnology in that time was the Lysenkoism accompanied the close ties to the Soviet Union. Lysenkoism refers to the Soviet minister of Agriculture, Trofim Lysenko, who denounced the study of genetics (EMBO, 2003).

When biotechnology research started in the early years of post-reform China, it was focused on agriculture and pest resistant crops in particular. A more thorough overview of the activities and particulars of agricultural biotechnology follow after a discussion on the policies which affected the growth of the biotechnology sector the most. After agricultural biotechnology follow an overview of the life science subsector of biotechnology. Life science includes biopharmaceuticals and other health related treatments.

For the early years there are no reliable statistics on the amount of researchers, expenditure or patents granted with regards to biotechnology. However, there are estimations of the number of research staff employed and research expenditure provided by Huang *et al* (2003):

Table I

Estimated scope of Chinese biotechnology in the early years

Year	Research Staff	R&D expenditure (RMB m at 2000 prices)
1986	740	38
1990	1067	68
1995	1447	87

Source: Huang et al (2003)

Although the estimated numbers in Table I are not conforming to the definitions of the statistical yearbooks published by the National Bureau of Statistics in China, the estimation point towards a rough doubling of both research staff and R&D expenditure of the 1986-1995 time span. The estimations are compiled from interviews with Chinese officials and researchers active in the time period (Huang & Wang, 2003).

It was not until 1996 that biotechnology research statistics appeared in the statistical yearbooks, but up until 2010 they did not feature the breakdown for both type of industry and registration status. Presented below is the historical statistics on the amount of firms, the total income of all firms, the full-time equivalent R&D personnel and the intramural R&D expenditure used in the Chinese biotechnology sector:

Table II

Biotechnology industry scale in China 1996-2007

Year	Number of firms	Total income of all firms (RMB bn)	Full-time equivalent R&D Personnel (man year)	Intramural R&D Expenditure (10,000 RMB)
1996	433	8987	1173	4238
1997	411	10500	1034	7128
1998	240	8441	1058	5176
1999	257	9672	1194	8463
2000	271	13570	1406	16571
2001	305	17090	1665	21343
2002	335	19340	1401	16772
2003	352	24690	1147	15241
2004	435	20960	1235	16769
2005	478	35370	1534	22955
2006	527	43880	1706	30592
2007	622	60100	2769	55225

Source: High-Technology Yearbook (National Bureau of Statistics, 2002-2008)

Note: The years covered here only includes large and medium sized firms as defined by the National Bureau of Statistics with a requirement of .5bn RMB and 50m RMB respectively.

From Table II the growth of the Chinese biotechnology sector can be examined for the time span 1996-2007. Comparing the numbers from 1996 with the number of 2007; the total amount of firms have increased with about 44 percent, the total income of the firm with 567 percent, full-time equivalent R&D personnel with 136 percent, and intramural R&D expenditure with roughly 1200 percent. Worth noting is also that there seems to be quite a leap happening between 2006 and 2007. In just one year, the number of firms increased around 18 percent, the total income with almost 40 percent, full-time equivalent R&D personnel with 62 percent, and intramural R&D expenditure with about 80 percent.

This great leap from 2006 to 2007 could be explained by the increasing number of Chinese expatriates who return to China after receiving higher education abroad. Of the nearly 450,000 Chinese overseas students in 2010 about one-third are engaged in study or research related to biotechnology. And about 25 percent of those that have studied subjects related to biotechnology overseas have returned to work in China (Chen *et al*, 2011).

Even though the Chinese biotechnology industry originally stems from state-owned firms and institutes, Chinese authorities have in an effort to boost linkages between state-owned institutes and private industry, encouraged scientists to establish their own companies. Scientists are even offered the option of keeping their academic position for a limited amount of time (EMBO, 2003). But this raised concerns for the protection of intellectual property among scientists, especially with regards to the protection of newly invented technology. But with the entrance of China into the WTO the Trade-related Aspects of Intellectual Property Rights (TRIPS) agreement has been implemented. Even before the WTO entrance, Chinese lawmakers signalled strongly that intellectual property was to be protected, and a commonly used example of this intent is that between 1998 and 2002 almost 24,000 IP cases were adjudicated (Li, et al., 2004).

For international comparison, as one of the very high technology sectors, biotechnology R&D is difficult to specify and collect the needed data. Recent international comparisons like the European (EuropaBio, 2006) and the Ernst & Young Global biotechnology report (2012) both note the difficulty of internationally comparable data and does not feature developing nations such as China. To look at the biotechnology sector in China, the OECD published the OECD Reviews of Innovation Policy (2008); it notes that the investments in R&D has come to be an increasingly large part of the foreign direct investment (FDI) received by China. Especially biotechnology has formed clusters of FDI primarily around Beijing and Shanghai but recently also in Guangdong, Jiangsu and Tianjin. The primary motivations for the foreign biotechnology firms to establish themselves in China include the large pool of well educated and highly skilled workers, often educated in Europe or the United States. Other factors, such as government programs and R&D reform played a lesser role (OECD, 2008).

To get a sense of the Chinese biotechnology competitiveness, expenditure on R&D as a percentage of GDP is often used as a crude measure of the innovative capacity of a nation. But expenditure does not reveal efficiency. Countries and firms could spend a lot of resources on R&D for very little return. Presented below is the R&D expenditure as a percentage of GDP from 1996 to 2008, comparing China with the United States, Japan, UK, Germany and France:

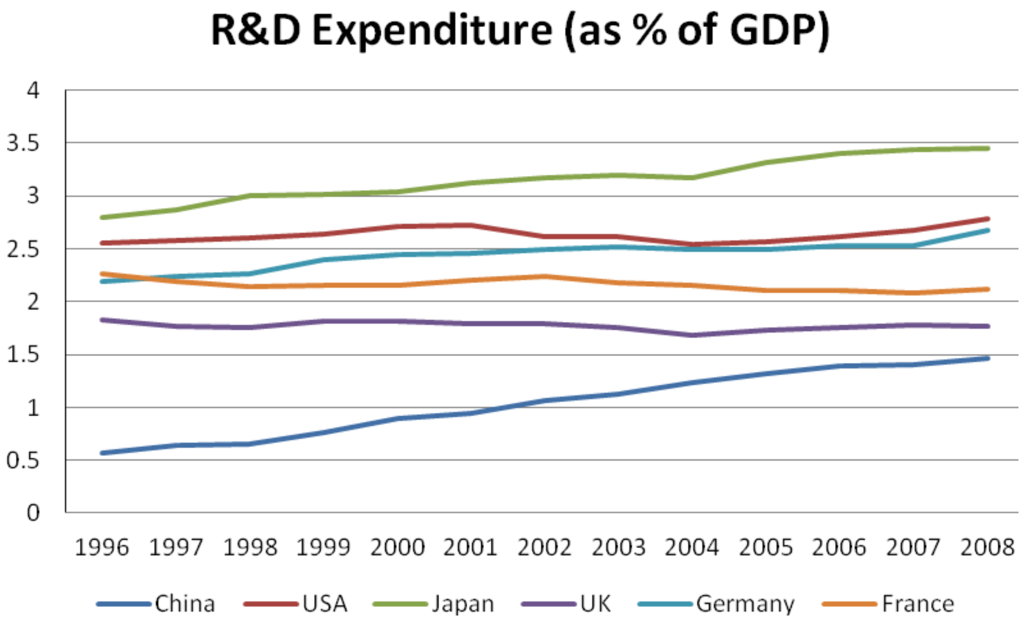

Figure I. Source: The World Bank

Visible in the graph, although China has increased its R&D spending as a percentage of GDP from about 0.6 percent to 1.5 percent, China is still behind the developed nations in spending. A recent study by Sharma & Thomas (2008) however, used data envelopment analysis to examine R&D efficiency of 22 countries while incorporating a time-lag. They look at the patents granted to residents and the number of publications as the output and spending on R&D, researchers per million inhabitants, population and GDP. The input variables were from 2002 with the outputs at 2004. Findings showed that many countries were not using their resources for R&D efficiently and the only countries found to be efficient under both constant and variable returns to scale was Japan, Republic of Korea and China.

Policy

China's efforts in biotechnology has not been ad hoc but instead tailored to meet the specific problems observed as it went along. Below follows a table containing the major policies implemented by the Chinese government since 1982 related to the biotechnology sector:

Table III

Summary of major policies affecting biotechnology research

Year	Policy	Major features
1982	Key technology R&D program	Stimulation efforts in key technologies
1985	Patent Law	Instituted patents
1985	National Key Laboratories on biotechnology	Thirty National Key Laboratories on biotechnology are established under MOST
1985	Resolution on the reform of S&T system	Adopting flexible system on R&D management
1985	Sparkle system	Encouraging basic research in agriculture
1986	Natural Science Foundation of China	Establishes the Natural Science Foundation of China, support include life science and agronomy
1986	Project 863	High-tech promotion, biotechnology is one of seven promoted sectors
1988	Torch program	High-tech commercialisation, high-tech zones
1988	National biotechnology development policy outine	Outline prepared by MOST and SDPC. Defined the research priorities, the development plan and measures to achieve the proposed targets
1990	National S&T achievements spreading program	Encouraging product commercialisation
1991	National engineering technology research program	Technology transfer and commercialisation of research projects
1992	Climbing program	Promoting basic research, including biotechnology
1993	Biosafety regulations	Regulation of genetic engineering with biosafety grading and safety assessment, application and approval process
1993	S&T progress law	Technology transfer, S&T system reform
1995	Decision of accelerating S&T progress	Encouraging URI-industry linkage
1995	Project 211	Increase funding for universities with the goal of raising research standards
1996	Law for promoting commercialisation of S&T achievement	Regulating the commercialisation of S&T achievement
1996	Super 863 program	Commercialisation, break-through in key areas
1997	Project 973	Increased funding for basic research including life science
1997	Agricultural GMO biosafety committee	The GMO biosafety committee was set up within the MOA
1998	Project 985	Creating an Ivy League among the universities with additional funding
1999	Decision on developing high-tech and realising industrialisation	Promoting technology innovation and commercialisation
1999	Special foundation for transgenic plant research and commercialisation	A five-year funding initiative to promote research and commercialisation of transgenic plants in China
2000	Guidelines for developing national university science parks	Accelerating the development of university science parks
2000	Seed regulation and law	Seed law regulating and protecting new varieties of plants
2002	Foreign investment in GMO ban	GMO is put as a prohibited area for foreign investment
2006	The S&T Strategic Plan for the Development of Science and Technology	New guidelines for future policy with focus on indigenous innovation and leapfrogging in key areas including biotechnology

Source: Huang & Wang (2003), Li (2004), Zhong & Yong (2007) and OECD (2008)

The goals for the biotechnology policy and programs implemented since the early the 1980s were multifaceted. The first goals defined by the Chinese government were improving the nation's food security, increasing the income of farmers, creating sustainable agriculture development, improving human health and the environment and to create a competitive agriculture and life science industry raising it to the standard of the already developed countries. To reach these goals, the government has implemented several key policy measures. These measures includes the establishment of a comprehensive financed public research and development system, the creation of institutions and regulation to improve health conditions by new technology, investment in innovative capacity and stimulation of industrialisation of biotechnology by giving high priority to research programmes involving the private sector (Huang & Wang, 2003).

A plethora of ministries and state bureaus are responsible for crafting and implementing the new policy. The most prominent of these are the Ministry of Science and Technology (MOST), the State the Development and Planning Commission (SDPC), the Ministry of Agriculture (MOA), the Chinese Academy of Sciences (CAS) and the Ministry of Education. Under these ministries and institutions there are numerous academies, institutes and laboratories conducting biotechnology research. In addition, there are many Key Biotechnology Laboratories (NKL) and other programmes operating at the provincial level (Huang & Wang, 2003).

The "Key Technology R&D Program" of 1982 was initiated with the aim of promoting key technology research in the fields of industry, agriculture and social development. In 1985, two major policies were released in the form of "Resolution on the Reform of the S&T system" and the "Sparkle program". The former had two primary objectives: to improve the overall R&D system management, including promoting research personnel movement, and to integrate science and technology into the economy. The "Sparkle program" instead focused on rural areas and encouraging research into agriculture (Zhong & Yong, 2007).

One of the most important programs for high technology research was the "863 program" initiated in 1986. It established eight priorities areas of research: biotechnology, automation, energy, ocean, laser, marine, advanced materials and information technology. These priority areas were to be leapfrogged to the cutting-edge of scientific research. To accomplish these goals, education in these areas were expanded and more than 10 000 scientists were mobilised for 2860 projects per year. The "Torch Program" of 1988 was implemented to further the establishment of high technology enterprises. It eased regulations and promoted the establishment of indigenous high technology firms in special zones all over China. It also provided support for constructing facilities to be used attract foreign high technology firms. These zones were located in close proximity of the existing research institutes in order to establish linkages between the new firms and the researchers. Main industries for these zones were information technology, new materials, energy technology and biotechnology (Zhong & Yong, 2007).

In 1990 the “National S&T Achievements Spreading Program” was implemented to increase technological achievements. Furthermore, with the continuing efforts to promote technology transfer and commercialisation of research products from academia; financial support was cut and greater autonomy was given to research institutes. One of such efforts to grant greater autonomy was the enforcement of the “National Engineering Technology Research Center Program” of 1991. Basic science was addressed in the “Climbing Program” in 1992 and provided funding to universities. The “S&T progress law” provided some transparency through peer review of proposed projects and institutional performance. Linkages between research institutes were the reason behind “Decision on Accelerating S&T Progress” in 1995 but it took until 1994 to begin the policies. Both programs of “Decision on Developing High-Tech and Realising Industrialisation” and “The Guideline for Developing National University Science Park” were established to continue the commercialisation efforts of science and technology and establish science parks around the most prominent universities (Zhong & Yong, 2007). Project 973, also called the National Basic Sciences Initiative, was launched in 1997 with a budget of 2.5 billion RMB to exclusively fund basic research. Biotechnology was one of the priority recipients under the project (Huang & Wang, 2003).

The latest major policy framework is the S&T Strategic Plan for the Development of Science and Technology. This plan is the outcome of a national conference on science and technology that was held in January of 2006. China’s continued growth was considered to be blocked by six factors such as dampening social developments, the imbalance between the rural and urban areas with regards to economic conditions, the negative externalities on the environment by the rapid industrialisation, the disparity between economic growth and job creation, the lock-in by manufacturers in low value-added production and that the catch-up process relies heavily on imported technology. To remedy these problems the plan emphasises 4 main strategies: indigenous innovation, leapfrogging in key areas, S&T supporting economic and social development and S&T leading the future. By 2020 the targets proposed would mean that China should have a ratio of gross expenditure on R&D to GDP at 2.5 percent (OECD, 2008).

Some educational policies also deserve mention. Even though they are not specified as policies for innovation and research they have provided the foundation in brainpower that is required for an innovation economy. Perhaps the most famous one is "Project 211" which aims at strengthening around 100 higher education institutions through increased funding. Together these institutions accounts for the lion's share of state research. Besides "Project 211" another project named "Project 985" was introduced in 1999. This new project aimed at creating world-class universities in China and initially only Peking University and Tsinghua University were a part of this program. Later another 7 universities were added to the program. Similarly to "Project 211" the instrument to accomplish the stated goal is primarily a great increase in funding (Li L. , 2004).

There educational programs have not only provided basic research but also vastly increased the talent pool available for companies thus enabling higher value-added industries. A study by Sun *et al* (2006) explored the reasons for foreign R&D firms to establish themselves in Shanghai. They conducted interviews with 18 foreign firms and concluded that one of the main reasons were the abundance of skilled scientists and researchers. Further, R&D in China by foreign firms was in general adaptive and meant to serve the Chinese market but long-term strategic R&D for the world market is also present.

Agricultural Biotechnology

Initially the focus of agricultural biotechnology development was on tissue culture, cell engineering, cell fusion, and stress tolerance, and the emphasis lied on crops such as rise, maize, vegetables, wheat and cotton (KLCMCB, 1996). But it was following the transgenic techniques developed in 1983 that agricultural biotechnology really took off. And later when Project 863 was implemented, the whole field of biotechnology research accelerated further.

In the early years, top priority was assigned to insect and disease resistance but more recently improved quality of the crops have become increasingly important due to market demand for quality (Huang & Wang, 2003). With the increase in demand for quality also came increased demand for biosafety. Before the 1993 regulations on biosafety, the safety testing was up to the producers of the specific products and this was a great concern for consumers. Not only domestic consumers objected but foreign trade partners refused to import various genetically modified crops, tobacco in particular. The regulations for biosafety first passed in 1993 have been updated several times over the years to broader concerns in the field of health concerns and the environmental impact of GMOs. Several surveys on the public acceptance of GMOs have been undertaken but the results appear to be very location and time dependent (Karplus & Deng, 2007).

Arguably the most successful agricultural biotechnology development in China is *Bt* cotton (*bacillus thuringiensis)*. Natural cotton has historically been ranked as one of Chinas most important economic crops but when pesticide resistant bollworm started emerging in the 1980s, scientists began researching cotton with genetic modifications. Starting by taking a gene from the bacteria *bacillus thuringiensis*, the scientists managed to transfer this gene into the cotton with the use of the pollen-tube pathway transformation method. Testing in greenhouses began in the early 1990s and the final crop was approved for commercial release in 1997. Later in 1997, *Bt* cotton varieties became available to farmers from publicly funded research institutes and from a joint-venture with the US firm Monsanto. *Bt* cotton was the first large scale commercial product developed by China's biotechnology research programme. From 1997 to 2001 the land used for *Bt* cotton as a percentage of total cotton cultivation land use in China when from 1 percent to 43 percent (Huang & Wang, 2003).

Other transgenic plants were give resistance to insects, herbicides, disease, and stress tolerance. In addition, some crops and plants with improved quality have been approved for field testing and others are near commercialisation. These plants included cotton with fungal resistance, rice resistant to bacteria and wheat resistant to viruses (Cheng, et al., 1997), maize with resistance to insects and vastly improved quality (Zhang, et al,. 1999), poplar trees resistant to harming moth, transgenic potato with resistance to disease, herbicide resistant soybeans and more. Apart from resistance for crops, other progress has been made in the field of plant biotechnology such as microorganisms in the form of bacteria for soybeans, rice and corn. For example, genetically modified nitrogen-adjusting bacteria have been commercialized since 1999. Further, Chinese researchers announced in 2002 that they had successfully sequenced the rice genome and that they have produced a draft sequence for the most widely cultivated rice subspecies (Huang & Wang, 2003).

When it comes to animal biotechnology, China has also made great strides. Spurred by increased meat and fish consumption due to the increased income among the population, China has put much resources into transgenic animals that could be used for consumption in the future. Scientists have successfully cloned rats, goats, cattle, and carp, and have the ability to extract medicinal proteins from these animals (Chen. et al., 2007).

Life Science

Even though they entered the the Human Genome Sequencing project late, Chinese scientists contributed around 1 percent of the whole sequence. In addition, around 1000 full-length cDNAs of novel genes has been published for the project by Chinese scientists (Chen, Wang, Wen, & Wang, 2007). China used the Human Genome Sequencing project to kick-start their genetics research by using the 56 distinct ethnic groups residing within its borders. The information collected was saved to a comprehensive knowledge base for future research into biomedicine. Chinese scientists also welcomed the opportunity to work with western geneticists and biologists (EMBO, 2003).

The outbreak of SARS in 2002 made the flaws of the biotechnology field and regulation in China apparent. The Beijing Genomics Institute was tasked with sequencing the SARS virus they were well positioned in terms of qualified personnel and available equipment, but when they travelled to the infected zones in southern China to collect the samples, they not allowed in. That regulation prohibited the transfer of the virus was the official reason given but suspicion has grown that competition between research institutions and political concerns hampered the collaboration. Beijing Genomic Institute finally gained access to the virus after a group of researchers in Vancouver, Canada posted the entire genome sequence on the internet. In general, the lack of collaboration between institutions and industry have been a known flaw in China's biotech sector but since the SARS outbreak there have been signs of increased collaboration (Li, et al., 2004).

In 2003, the Shenzhen firm SiBono GenTech was the first company in the world to obtain a drug licence for a recombinant gene therapy. The drug, aimed at treating neck and head cancer was approved by China's State Food and Drug Administration after clinical trials lasting over five years showed an acceptable side effect profile. A total cost for the development of the therapy was estimated to 9.6 million USD, in addition to research grants from the government and the years of clinical trials. As China has hundreds of thousands of patients who die because of cancer every year, gene therapy is seen as holding great promise, but the results have so far not lived up the expectations (Li, et al., 2004).

Recent developments in life science in China have consisted of vaccines for Hepatitis B (Li, et al., 2004), better ways to accomplish protein production by animal cell culture which have medical and veterinary applications (Zhang Y. , 2009), progress in desulfurization of fossil fuels which could help reduce environmental pollution (Xu, et al., 2009), and new methods in wastewater treatment with the use of aerobic granular sludge (Liu, et al., 2009).

IV. Data and Method

Data

The data for this study was collected from the High-technology Yearbook of 2010 published by the National Bureau of Statistics of China. It has breakdowns of the data on high-technology enterprises into various different entities and the one in focus here is the breakdown on sector and registration status for 2009. This breakdown of the data is not available for years prior to the yearbook of 2010. Instead, earlier yearbooks include data broken down into industrial sectors but only for state-owned enterprises and joint-ventures. Another drawback is also that earlier data focuses exclusively on large and medium sized firms. As discussed previously, biotechnology is in large parts created by small innovative firms, this makes the use of data from prior to the yearbook of 2010 unwise.

Data envelopment analysis is very sensitive to choosing the wrong variables as the variables cannot be tested for significance, the variables selected have been used by Chiu *et al* (2010) Zhong *et al* (2011). Four different registration statuses are included: domestic funded enterprises, state-owned enterprises, enterprises with funds from Hong Kong, Macau and Taiwan and lastly foreign funded enterprises. The collected variables are drawn from the manufacture of biological and biochemical chemical products under the manufacture of medicines category in the statistical yearbook. The variables used are presented as follows:

- Patent application for invention patents in 2009 measured in units. Used as the output variable.
- R&D personnel refers to the number of research workers, engineers, designers and scientists measured by 10 000 person units.
- Intramural expenditure on R&D refers to the expenses of an enterprise for researching and developing technology, know-how and patents by oneself which are measured in 10 000 RMB. This variable has excluded equipment expenditure and government funds.
- Equipment expenditure refers to the expenditure for purchasing of instruments and equipment for R&D purposes. Measured in 10 000 RMB.
- External expenditure refers to expenses for licensing or purchasing technology from other domestic of foreign enterprises. Measured in 10 000 RMB.
- Government funds refers to the expenditure provided for by the government, measured in 10 000 RMB.

Table IV

Input and output data

Registration status	Invention patent applications	R&D personnel	Intramural expenditure on R&D	Equipment expenditure	External expenditure on R&D	Government funds
Domestic private enterprise	573	7474	94025	17978	13874	12406
State-owned enterprise	34	1039	14081	3758	660	1825
Enterprises with funds from Hong Kong and Taiwan	121	2287	27029	5690	1020	991
Foreign funded enterprises	106	1584	20591	3348	1664	1155

Source: High-Technology Yearbook (National Bureau of Statistics, 2010)

The use of patents statistics as an indicator of innovation has been discussed on multiple occasions in literature, starting with Maclaurin (1953). Maclaurin also proposed using the total expenditures for R&D and the number of research worker to study the propensity to invent in firms and economies. Two researchers, Pavitt (1985) and Griliches (1990), examined the studies using patent statistics in that time and concluded that even though there are problems, especially in international comparison, patent data is useful for the study of technical change. More recently, the Oslo Manual published by the OECD (2005) on how collect and interpret innovation data argues that despite drawbacks such as the difference in values between different patents and that many innovations are not patented has positive sides and are useful for assessing innovation. In the context of this study there is another caveat; foreign firms are likely to apply for patents in other countries rather than China as to maximize the protection received.

Chinese economic statistics are considered fairly reliable by Chow (1993) for a transition economy. He argues that the official statistics reported by the state to be by and large honest even though problems exist. Factors that affect the quality of the statistics are concluded to be the limited training of the officials, the limited resources for the state statistical bureau for collecting, processing together with the possibility of political pressure to falsify statistics by the reporting units. Further, the statistics are argued to be internally consistent and accurate enough for a number of studies including studies on econometric models of inflation and general studies of the Chinese economy.

This claim is disputed by Rawski (2001) who examined the GDP statistics from 1998 to 2001 and found large inconsistencies. One major inconsistency was the dropping energy usage in the same time the economy is thought to have grown at approximately 24 percent and no rapid growth in energy efficiency was apparent. Other issues were the increased farm output at the same time of major flooding and a great increase in investment spending while cement output and steel consumption only showed modest increases. This was again countered by Chow (2006) who asserts that official Chinese statistics are on par with other developing countries and that hard evidence of data manipulation is relatively scarce. Also, since official plans are based on these statistics there is little incentive for centrally instigated tampering but general caution is advised as is common with developing countries.

The data used for this study certainly comes from an area of importance and prestige for the Chinese government which gives an incentive for overly optimistic statistics to be produced, the same statistics is used by the government institutions for policy evaluation such as the study by Zhong *et al* (2011).

Method

The foundation of efficiency measurement is attributed to Farrell (1957), who suggested that the efficiency of a production unit consisted of two components: technical efficiency and allocation efficiency. Technical efficiency refers the ability of an entity to achieve maximum output given a set of inputs while allocation refers to the ability of an entity to use the inputs in optimal proportions. Farrell then suggested combining technical efficiency and allocation efficiency to get a measure of total economic efficiency.

The empirical methodologies for efficiency analysis are split into two groups: parametric and non-parametric. Both methods establish production frontiers albeit in different ways. Stochastic frontier uses the production function to estimate the optimal production possible while data envelopment analysis utilizes linear programming to compose a frontier of all the examined decision making units (DMU) (Coelli, 1996). Presented below is a summary of the different characteristics between stochastic frontier analysis and data envelopment analysis:

Table V

Summary of SFA-DEA comparison

Method	Stochastic Frontier Analysis	Data Envelopment Analysis
Characteristic	Parametric	Non-parametric
Description	Uses the production function (or other functions) to describe the production technology and estimating technical efficiency	Uses the linear programming to estimate the frontier. The method provides analysis of relative efficiency by evaluating each DMU and measuring its performance relative to the frontier composed of the other DMUs.
Advantages	Allows for testing goodness of fit hypothesises for the model	Does not require the specification of the production function
Disadvantages	Imposes parametric structures on both the distribution of inefficiency and technology, making it susceptible to specification error.	Not possible to estimate parameters of the model and therefore impossible to test the performance of the model

Source: Ajibefun (2004)

A paper by Ajibefun (2004) compared the two methods on small scale farms in Nigeria and found that the models produced very similar results. Therefore for this study, data envelopment analysis will be used as it requires fewer assumptions and are thus less susceptible to misspecification.

The formula proposed by Farrell (1957) had severe limitations due to the difficulty of calculating with certainty the average attributable to any one input as the inputs and outputs increase. It was not until Charnes *et al* (1978) formulated it as a linear programming problem which could be solved by the simplex algorithm the problem was solved. They also coined the term data envelopment analysis (DEA). The model the proposed by Charnes *et al* measured the technical efficiency of the entity relative to a reference technology which exhibited constant returns to scale at every point on the production frontier. This became the constant returns to scale model.

To overcome the restrictive nature of the constant returns to scale model, Banker *et al* (1984) developed the variable returns to scale model (VRS). This model generalised the original constant returns to scale model for technologies showing diminishing, constant or increasing returns to scale at different points on the production frontier. This is done by adding a convexity constraint. Further, they proposed that scale efficiency can be defined as the ratio of the constant returns to scale model technical efficiency to the variable returns to scale technical efficiency:

$$Scale\ Efficiency = \frac{CRSTE}{VRSTE} \tag{1}$$

The inefficiencies in data envelopment analysis is measured by what is called slacks. Due to the linear nature of non-parametric frontier in data envelopment analysis some problems in dealing with slacks can occur if the inefficiencies present themselves in two or more dimensions. The sum of slacks is the distance between the inefficient firms production to the efficient frontier. In literature, there are three different ways of calculating slacks: one-stage, 2-stage and multi stage DEA. Recent studies have exclusively focused on multi-stage DEA as it has the benefits identifying efficient projected points which have output and input mixes that are as similar as possible to those of the inefficient points and also invariant to units of measurement. The only drawback of multi-stage DEA is that it is computationally more demanding. The multi-stage DEA will therefore be used in this paper.

Apart from the standard CRS and VRS DEA models there are extensions of these models to account for allocation and cost efficiencies and the Malmquist-index which processes panel data to calculate indices of total factor productivity (Coelli, 1996). For this study the standard models are chosen as panel data is not available. When more data with the same structure becomes available a DEA Malmquist index could be created but it is not possible at this time. Cost or allocative efficiency is not the focus of this study and therefore not used.

The choice between output and input orientation of the model depends on the importance of input conservation or output augmentation. As the aim of this study is to examine whether state-owned enterprises uses their inputs as efficient as private firms and highlight the efficiencies or inefficiencies in resource use, the input model with variable returns to scale is chosen. To calculate this model the DEAP 2.1 program from the Center for Productivity Analysis website is used.

V. Results and Discussion

Results

The result from the VRS model is described in table VI below:

Table VI

Results from CRS and VRS DEA

Registration status	CRS Technical Efficiency	VRS Technical Efficiency	Scale Efficiency	Returns to scale
Domestic private enterprise	1.000	1.000	1.000	Constant returns to scale
State-owned enterprise	0.571	1.000	0.571	Increasing returns to scale
Enterprises with funds from Hong Kong and Taiwan	1.000	1.000	1.000	Constant returns to scale
Foreign funded enterprises	1.000	1.000	1.000	Constant returns to scale

The results show that all ownership forms exhibit full technical efficiency under variable returns to scale and that all forms except state-owned enterprises lay on the production frontier with constant returns to scale. As they lie on the production frontier they are also scale efficient. State-owned enterprises instead have an efficiency score of 0.571 in the constant returns to scale model which if taken without the variable returns to scale would indicate that inputs could be reduced by 42.9 % and still produce the same output. As they exhibit full efficiency under the variable return to scale model the issue instead becomes a problem of scale. State-owned enterprises show increasing returns to scale from the calculated model, a result that will be tested in a sensitivity analysis and discussed further in the next part. Worth noting is also the result that domestic private firms are found to be equally efficient as enterprises with funds from abroad.

One of the benefits of data envelopment analysis is the ability to examine the slacks calculated from the model and look at the changes in inputs needed to achieve efficiency. As shown in table VII, R&D personnel could be reduced by 42.9 percent, intramural expenditure reduced by 14.9 %, equipment expenditure reduced by 62.6 %, external expenditure reduced by 42.3 % and government funds by 82.3 % in order to reach scale efficiency.

Table VII

Change in variables needed to reach scale efficiency for state-owned enterprises

State-owned enterprise	Invention patent applications	R&D personnel	Intramural expenditure on R&D	Equipment expenditure	External expenditure on R&D	Government funds
Original Variables	34	1039	8498	3758	660	1825
Projected Efficient Variables	34	593.4	7232.8	1406.9	376.9	312.1
Difference	0	-445.6	-1265.1	-2351.1	-283	-1512.9
Percent change	0	-42.9 %	-14.9 %	-62.6 %	-42.3 %	-82.3 %

Sensitivity Analysis

As data envelopment analysis cannot be tested for the goodness of fit for the model in the same way as econometric models, other tests are needed. What can be tested is if the results for the DMUs found to be inefficient stay the same even if the method for calculating the distance to the frontier is changed. In the main DEA model, multi-stage slack calculation was used to calculate this distance. In order to test the results and scale efficiency of the inefficient DMU (state-owned enterprises) two models using 2-stage slack calculation is used. The 2-stage slack calculation indentifies the furthest efficient point from inefficiency, which is a problem if the DMU is inefficient in more than one dimension. In essence, this sensitivity analysis tests if the inefficient DMU is inefficient in more than one dimension. The models calculated are a CRS model calculated in 2-stage and another VRS model calculated in 2-stage. The 2-stage DEA models are presented below:

Table VIII

Sensitivity analysis using additional DEA models

CRS 2-stage		VRS 2-stage			
Registration status	CRS Technical Efficiency	CRS Technical Efficiency	VRS Technical Efficiency	Scale Efficiency	Returns to scale
Domestic private enterprise	1.000	1.000	1.000	1.000	Constant returns to scale
State-owned enterprise	0.571	0.571	1.000	0.571	Increasing returns to scale
Enterprises with funds from Hong Kong and Taiwan	1.000	1.000	1.000	1.000	Constant returns to scale
Foreign funded enterprises	1.000	1.000	1.000	1.000	Constant returns to scale

As shown in table VIII, the results from the two models using 2-stage DEA instead of multi-stage yield are the same as the main model. State-owned enterprises are only inefficient in one dimension. It is also interesting to note that all ownership types are found to be efficient on the variable returns to scale frontier regardless of the choice of slack calculation method.

Discussion

The results of this study show that domestic private firms, enterprises with funds from Hong Kong and Taiwan and foreign funded enterprises all lay on the production frontier and are fully efficient. State-owned enterprises however, are found not to be scale efficient but at the same time efficient in the variable returns to scale model. This result is consistent with the hypothesis examined. When looking at the cuts in inputs needed to achieve scale efficiency for state-owned enterprises expenditure for government funds and equipment expenses sticks out by requiring very large cuts, further supporting the theory of state-owned inefficiency. Variables that would test the theory head on such as R&D projects started, projects cancelled, project duration, project outcome are not available. Instead, government funds used as expenditure in particular but also the over usage of inputs in the production of innovation patents further strengthens the theory. Even as state-owned enterprises exhibit increasing returns to scale, that increase in outputs per inputs only occurs should the firm make efficient choices on what projects to undertake.

A recent study by Chen *et al* (2012) examined the impact of ownership structure in China on innovation performance and found that mixed ownership between state-owned, private and foreign ownership performed the best. The data used by Chen *et al* (2012) was taken from the Shanghai and Shenzhen stock exchanges and China (Mainland) Industrial Censuses, using listed firms during the years 2004 to 2006. They do not specifically include any biotechnology firms as a part of their sample and chose to measure innovation output as the yearly market value of new products normalized by the number of employees. Further, the authors measure innovation efficiency as the coefficient of R&D intensity for innovation output. This has the problem that new products need not be innovations.

Xu & Zhang (2008) studied the impact of state share on corporate innovation strategy and found that state shares had a positive impact on the corporate choice of putting R&D resources in into the production process rather than new products. Moreover, firms with a large state ownership share achieve better innovation performance. The data in gathered from publicly traded high-tech companies (including pharmaceuticals and chemical companies) traded on Shanghai and Shenzhen stock exchanges, then the company's annual reports are scanned for innovation events which are then constructed into variables.

Using data from the Haidian District of Beijing, Hu (2001) examine to what degree the cross-sectional variation in productivity can be attributed to differences in R&D expenditure. He found a strong link between firm productivity and private R&D investment but no link state-owned firms. His data is from a small pocket in China which enables him to account for differences in technical performance across the ownership types. However, it's difficult to draw conclusions for the whole of China with such a limited dataset. A study by Zhang *et al* (2003) estimated the operational and R&D efficiency of 8421 Chinese firms from the 1995 General national survey using stochastic frontier analysis. Main findings included that the state-owned enterprises had lower productive and R&D efficiency compared to private firms and even lower than foreign firms. But as their analysis was based on firm level data in all technology levels it is difficult to draw conclusions for biotechnology.

VI. Concluding Remarks

As governments and intergovernmental organizations have become increasingly focused on the need for innovation in order to ensure economic growth and an increased standard of living, the need has arisen to examine what factors influence the efficiency of research and development in order get the most out of the investment. One of the most heavily promoted sectors is biotechnology; pharmaceuticals, fertilizer, genomes and more. The field of biotechnology is also one where there exists economic theory on the impact of ownership structure for R&D. The theory suggests that for biotechnology, private ownership and its accompanying harder budget constraint will outperform government ownership or government guarantees, for example in the form of bailouts should the firm go bankrupt. Earlier studies that have looked at the ownership impact on R&D efficiency in China and elsewhere have used general firm data which cannot support or disprove the theory. As the theory states, the soft budget constraints enjoyed by government supported firms can sometimes be a benefit and sometimes a hindrance.

For government policy this has important implications. In the biotechnology field direct institutes and research firms are not to be recommended but there are other important tasks the government can do to foster biotechnology. As discussed earlier in the paper, the one of the main reason that foreign companies open research facilities in China has been the vast amount of highly educated and highly motivated scientists and researchers. The universities that have received extra funding through project 211 and 985 have risen substantially in the rankings and now deliver the skilled workers to the biotechnology firms. Further funding to the already benefiting universities and additional ones may be warranted as the industry grows outside the current main areas of Beijing, Shanghai and Guangdong.

Another reason to invest in the universities is the basic research they perform which benefits the private sector indirectly. This is common throughout the world but as China's reforms have worked on establishing linkages between universities and private firms (even foreign ones) here is an opportunity to shine. By investing in basic science and linkages the government money may be used more efficiently compared to direct research of research institutes. China has also made it possible for scientists working in universities and state research institutions to start private firms while keeping their university position for a limited amount of time. This is very much in line with the research theory examined in this paper and the results presented. While the state-owned enterprises and universities might lose valuable talent in the short run it may very well be of benefit to the whole of China in the long run. If anything, a policy which further encourages this behaviour should be looked into.

As more data becomes available with the same breakdown of the data, further studies could be undertaken to solidify the finding presented in this paper. One often desired feature in R&D efficiency research is the implementation of a time-lag in the model. Time-lags are often at 2-3 years between input and output to better reflect the connection between expenditure and benefit of R&D. Although, many studies do not have access to earlier data and therefore has to make the assumption that inputs stay relatively constant over time. Another benefit of additional data would be the possibility to create a Malmquist-index which measure changes in efficiency over time.

VII.

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