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Determinants of industrial innovation in China: Evidence from its recent economic census

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ABSTRACT

This study examines the sources of technological innovation in Chinese industries using the 2004 economic census data. On the one hand, it analyzes the relationships between patent grants and new product sales. On the other hand, it analyzes the relationships among in-house R&D, technology transfer from foreign and Chinese domestic technology markets, spillover effects of foreign investment, as well as export. The study reveals that in-house R&D has become the most important source for industrial innovation in China. In-house technological efforts are critical for developing original innovations as well as for absorbing the technologies transferred from external agencies. However, neither technologies transferred from foreign countries nor those from the domestic technology market are playing significant roles in China's industrial innovation. The spillover effect of foreign investment on patent grants is strong and significant, though its impact on new product sales is insignificant. Export shows negative, though insignificant, impact on patent grants, but positive, strong, and significant effects on new product development. Overall, the results of this study demonstrate the critical role of in-house R&D in China's industrial innovation.

1. Introduction

Technology is considered the driving force for regional and national economic development (Buswell, 1987; Malecki, 1991), and economists from Schumpeter (1954) to Romer (1994) have all emphasized the role of innovation. The recent rise of new growth theory and endogenous growth theory (Grossman and Helpman, 1994; Romer, 1994) has reemphasized the strategic role of technological advances in economic dynamics over time and space. Technological gap is one significant factor in explaining regional and international economical variations (Fagerberg, 1994; Fagerberg et al., 1997). As such, governments at all levels are allocating vast amounts of resources in invention, innovation, and education to promote economic growth and to enhance their economic competitiveness in the national and international markets (Malecki, 1991).

Industrial innovation is an important part of a country's national innovation system (NIS) and can come from different sources: in-house R&D, technology transfer from international as well as domestic markets, and the spillover effects from other industrial firms (Sun, 2002b). In the context of developing countries, particularly for those in the early development stages, technology transfers from foreign advanced economies (Ho, 1997; Walsh, 1999; Young and Lan, 1997) and the spillover effects from foreign investment (Blomstrom, 1986; Blomstrom and Persson, 1983; Blomstrom and Wolff, 1994; Caves, 1974; Globerman, 1979; Hu and Jefferson, 2002; Liu and Wang, 2003; Liu, 2002; Tian, 2007) have been considered the most important sources of innovation, since most such countries lack the capital and the talents to conduct state-of-the-art research. However, the importance of in-house R&D is critical for firms in developing countries as well. On the one hand, such efforts could enhance their absorptive capabilities (Bell and Pavitt, 1997; Cohen and Levinthal, 1989; Rosenberg, 1990), which are indispensable for monitoring and screening external technologies and opportunities, for successfully implementing technologies transferred from other sources, and for capturing the spillover effects from foreign investments. Such efforts are also important for domestic firms in developing countries to build their innovative capabilities. On the other hand, no countries are willing to be technologically dependent on other countries; achieving technological independence is considered by many as a matter of national security. As such, developing countries have natural urges to promote indigenous technology development (Correa, 1998; Katrak, 1998; Katz, 2001; Lu, 2000; Simon, 1989; Simon and Goldman, 1989; Sun, 2002a, 2002b).

Nevertheless, due to the complex relationship among R&D, technological innovation, and economic development, neither all in-house R&D can be easily translated into technological innovation nor are all technological innovations equivalent to market

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successes and competitiveness. In many cases, the linkages between in-house R&D, technological innovation, and market success are broken, due to institutional and organizational bottlenecks (Baark, 1987, 1992; Simon, 1989; Simon and Goldman, 1989; Sun, 2002a, 2002b; Suttmeier, 1980, 2002). Precious resources are wasted in many cases. As such, it is critical for developing countries to control the urge to become technologically independent, though it is difficult, if not impossible, to determine when exactly the appropriate moment is to start such efforts.

China, as a developing country, has witnessed tremendous economic growth during the last three decades, due to its adoption of the reform and open-door policies. Particularly important in this process is foreign investment, for which China has become the largest destination. In 2007, China attracted $74.8 billion and accumulated FDI (stock) has reached $760.2 billion (China State Statistical Bureau, 2008). FDI provides about one-quarter of China's industrial employment, 30% of its sales, and 57% of its export in 2004 (China State Statistical Bureau, 2005). While some have hailed China as the "model" for utilizing FDI, others have started questioning this strategy (Lo, 2006). Recent studies have found mixed empirical evidences regarding the role of FDI on domestic firms in developing countries (Aitken et al., 1997; Aitken and Harrison, 1999; Crespo and Fontoura, 2007; Hu and Jefferson, 2002), Huang (2005) even argued that China has gone too far in utilizing FDI and the strategy is not sustainable, since domestic firms are scarified. He argued for a more domestic-oriented strategy: develop indigenous technologies, promote domestic enterprises, particularly the private sectors, and expand domestic markets. The idea of developing indigenous technologies in particular has been well received in China. Since the middle 1990s, China has tried to build an industry-centered national innovation system and has dramatically increased its investment in science and technology (S&T). The research and development (R&D) investment intensity (the ratio between R&D investment and gross domestic product (GDP)) has increased from 0.6% in 1995 to 1.49% in 2007. In early 2006, China announced its "Guidelines for the National Medium- and Long-Term Science and Technology Development Program (2006–2020)" (The Levin Institute, 2006). In this program, the Chinese government has emphasized the strategic role of indigenous innovation (*zhizhu Chuangxin*) (The term *Zhizhu Chuangxin* has caused much confusion and has been translated into English many ways. A sample of such translations includes *independent innovation*, *indigenous innovation*, *internal innovation*, and *self-guided innovation*. When confronted with such a question, "What is *Zhizhu Chuangxin*?" in a conference on China's industrial innovation hosted by the Levin Institute, The State University of New York and the Council on Foreign Relationships in 2006, the vice Minister of China's Ministry of Science and technology replied, "All such translations are not accurate. The best translation is *Chuangxin* (or innovation)!" We adopt the second translation, which we feel probably reflects the intention of the Chinese government.), and proposed a number of measures in order to become an innovation-oriented country by 2020. The sudden growth of R&D investment has led Gao and Jefferson (2007) to claim that China is experiencing an "S&T take-off".

However, we are concerned about the efficiency of such R&D investment. We argue that without appropriate institutional reforms, the precious resources that have been devoted to S&T development will be wasted without generating significant scientific or economic contributions. A couple of recent studies have shown that in-house R&D is *negatively* associated with technological efficiency measured by total factor productivity (TFP) (Abraham et al., 2006; Sun, 2010). In this study, we adopt two different measurements of innovation: patent grants and new product sales. Using the recently published Chinese economic census data, we examine the determinants of industrial innovations in China. We argue that innovation measured by TFP does not necessarily come from R&D; technically, TFP measures the efficiency that a firm utilizes capital and labor in generating output. TFP can come from any source that improves efficiency: technological innovation, human resources, new management practices, or new business models. As such, it is a broad measurement of innovation. In our study, we use the more narrowly defined concept of innovation: new product or process technologies as measured by patents and new product sales. We are aware of the limitations of using patents to measure innovation, since firms in different sectors have different tendencies to apply for such protection and different patents have different economic significances. We are also aware of the problem associated with using new products to measure innovation, since there remains an ultimate question of "new" to whom. In the case of China's economic census, new products are defined as those that are new to the firm and are not necessarily original to the domestic or international markets. Nevertheless, new product development indicates "the occurrence of new or improved goods or services" (Fagerberg, 2006), though such products are not necessarily dramatically different from existing ones. Compared with TFP, we argue that these two innovation measurements bear more direct relationships with in-house R&D. In-house R&D is more engaged in new product development, which will not be translated to economic significance, if R&D efforts are not well integrated with production and marketing functions. It would be interesting to see whether results from this study are consistent with those from previous studies using TFP to measure innovation.

What follows in this paper is organized into five more sections. Section 2 briefly describes China's national innovation system and its recent technological drive. Section 3 reviews the literature on the sources of industrial innovation in developing countries. Section 4 describes the data and methodology while Section 5 presents the results. The final section concludes the study and discusses the implications in light of findings from previous studies.

2. China's national innovation system

China's national innovation system has experienced two major periods of development since 1949. During the first period before 1978, the state was the driving force of innovation, as the country followed the model of command economy. Governments, particularly the central government, funded and controlled all R&D activities. Innovation was operated through a top-down approach, centered on development of strategic weapons. Two features characterized China's NIS during this period (Liu and White, 2001; Sun, 2002a; Suttmeier, 2002). First, development of military technologies was separated from civilian technologies. Weaponry, particularly strategic weaponry, was China's priority from the early 1950s. China successfully developed a series of strategic weapons including nuclear weapons, strategic missiles, nuclear-powered submarines, submarine-launched ballistic missiles, atomic bombs, hydrogen bombs, and satellites in 1970 amid the chaotic Cultural Revolution (Feigenbaum, 1999). Such achievements came from China's own domestic efforts with no direct help from foreign countries when China was isolated.

The second feature of China's NIS for this period was the clear division of labor (separation) among industries, governmental laboratories, and universities (Simon, 1989; Simon and Goldman, 1989; Sun, 2002a). Industrial enterprises were centers of production; governmental laboratories focused on research and development; universities acted as training centers with a few exceptions. Governmental laboratories (those belonging to the Chinese Academy of Sciences, those administrated by different industrial ministries, and those belonging to local governments) were the major agencies directly performing R&D. There was little spontaneous interaction among industries, universities, and governmental laboratories either. These problems set the stage for reforms in the coming decades.

Reforms of China's national innovation system followed a gradualist approach. Earlier efforts of reforming China's NIS in the 1980s focused on improving technology transfer or what is characterized as an S&T strategy by Suttmeier (2002). The basic assumption of the S&T strategy was that the institutional division among governmental laboratories, universities, and industries was not the root of the problem. What was missing in the previous system was a dynamic linkage among these units, which were largely organized by the central government through vertical commands. Therefore, the major reform objectives were to create mechanisms that can foster interactions among governmental laboratories, universities, and enterprises. A variety of approaches were tried during this period: creating domestic technology markets, increasing the autonomy of government laboratories, facilitating mobility of S&T personnel, merging governmental laboratories with state-owned enterprises, and promoting spin-offs from universities and government laboratories.

Reforms in the 1990s were characterized by a shift from the earlier technology transfer approach to an innovation approach (Suttmeier, 2002) that centered upon industrial firms. Such a strategy clearly denounces the separation of R&D from industrial activities. The Central Committee of Chinese Communist Party (CCP) issued the "*Decision on various issues to build a socialist market economy*" after Deng Xiaoping's southern China tour in 1992. Regarding S&T policies, the decision proposed that industrial enterprises should become the primary force of technological innovation. The initiative received greater attention in 1995 when the central government held the National Science and Technology Conference in Beijing. Right after the Asian financial crisis, the Chinese central government held the National Technological Innovation Conference in Beijing in 1999, and issued the "*Decision on strengthening technological innovation, developing high-tech firms and realizing commercialization of new technologies*." The decision made an explicit call for the creation of a national innovation system, recognizing the intricate relationships among reforms in economy, S&T, education, and innovation. The importance of industrial R&D was further emphasized by these programs. Indeed, by 2005, industrial firms' R&D spending was about 70% of China's total R&D expenditure (Fig. 1).

China has witnessed tremendous growth of resources devoted to science and technology development. China's total S&T expenditure expanded from 38.9 billion yuan in 1991 to 709.9 billion yuan in 2007. Governmental S&T budgetary spending grew from 16.1 billion yuan to 170.3 billion yuan during the same period, and R&D rose from 34.9 billion yuan in 1995 to 371.0 billion yuan in 2007. R&D spending was about 0.6% of China's GDP in 1995 and by 2007 it grew to 1.49% (Fig. 2). Measured by outputs, similar drastic growth has been observed. Chinese domestic patent applications grew from 69,535 in 1995 to 586,498 in 2007, and the publications included by Science Citation Index, Index to Science and Technical Proceeding, and Engineering Index jumped from 26,395 in 1995 to 171,748 in 2006. China was ranked number fourth among all the countries regarding the number of publications included in such indices, right after the USA, the United Kingdom, and Japan. In early 2006, the central government announced its *Guidelines for National Medium- and Long-Term S&T Program* (2006–2020). The Chinese leadership clearly recognized the importance of indigenous innovation. The Chinese government aims to increase R&D investment from its current level to 2.5% of its GDP in 2020 (The Levin Institute, 2006), comparable to current levels in many advanced economies.

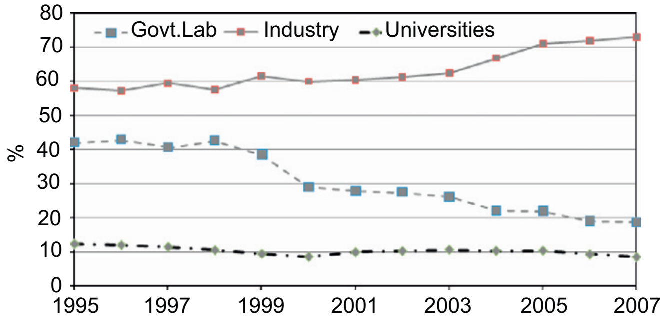

Fig. 1. R&D performed by different agents in China, 1995–2007.
Source: (Ministry of Science and Technology, various years), China Science and Technology Statistical Yearbook.

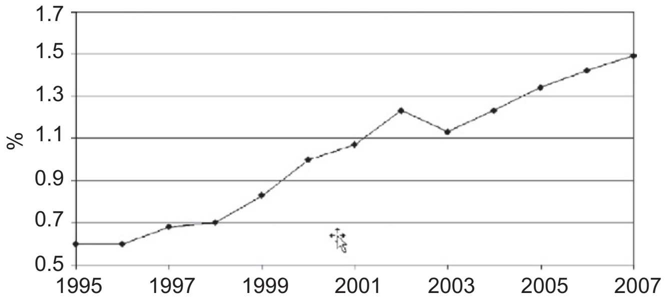

Fig. 2. China's R&D spending over its GDP, 1995–2007.
Source: (Ministry of Science and Technology, various years), China Science and Technology Statistical Yearbook.

However, the Chinese NIS has been plagued with many problems due to the legacies from the planned economy. Particularly, Liu (2008) has argued that many Chinese firms are reliant on imported technologies and have failed to absorb and develop their own innovative capabilities. Has this changed recently? Has China's S&T investment paid off (or started to pay off) in its technological innovation and economic development? Only a few studies have examined these issues (Gao and Jefferson, 2007; Hu and Jefferson, 2004; Hu et al., 2005; Jefferson et al., 2003; Liu and Buck, 2007; Liu and Wang, 2003; Liu and Zhao, 2003; Sun, 2002b), and mixed results have been found. We want to find what determines technological innovation in China's industries.

3. Sources of innovation in developing countries

Industrial innovations can originate from three major sources: in-house R&D, transfers from foreign as well as domestic agencies (Hu et al., 2005), and spillovers from other enterprises. In-house R&D refers to internal efforts of developing new products and processes. The literature has focused on the latter two categories in the context of developing countries. The experiences of many advanced economies from the United States to more recent examples such as Japan, Korea, and Taiwan have proved that the path of importation–imitation–absorption–assimilation–original innovation is a valid one for lagging countries (Nelson, 1993). Not surprisingly, efforts to analyze innovation in a transitional economy like China have largely ignored indigenous innovative activities, with a few exceptions (Lu, 2000; Lu and Lazonick, 2001). Instead, such efforts focus on technology transfer from foreign countries (Ho, 1997; Walsh, 1999; Young and Lan, 1997).

Also emphasized are the spillover effects from foreign investments where the spillover effects refer to the externalities for domestic firms due to the presence of foreign firms (Blomstrom, 1986; Blomstrom and Persson, 1983; Blomstrom and Wolff, 1994; Caves, 1974; Globerman, 1979; Hu and Jefferson, 2002; Liu and Wang, 2003; Liu, 2002; Tian, 2007). Dunning (1988, 1993) argued that foreign investors possess proprietary advantages compared to domestic enterprises so that they can overcome the challenges of operating in an unfamiliar environment. However, foreign investors will not be able to completely internalize such benefits, and domestic firms will learn from foreign companies through spillover channels including *demonstration/imitation*, *labor movement*, *exports*, *competition* and *backward and forward linkages* with domestic firms (Crespo and Fontoura, 2007).

Empirically, many studies have examined the possible spillover impacts of foreign firm since the pioneer study by Caves (1974) on Australia. Caves' study reveals positive spillover impacts of foreign investments on domestic firms. Following Caves' effort, a few other scholars have examined the issues in other countries, including the study of Globerman on Canada; Blomstrom (1986), Blomstrom and Persson (1983), and Globerman (1979) on Mexico; and Haddad and Harrison (1993) on Morocco. Such studies have largely confirmed the existence of positive spillovers from foreign investment. However, the study of Aitken and Harrison (1999) found negative impact of foreign investment on domestic enterprises in Venezuela, and this study rekindled the interests in this topic. A few recent studies have observed similar negative impacts of foreign investment on domestic enterprises and examples include the study of Djankov and Hoekman (2000) on Czech Rep., and of Kathuria (2000) on India. In the case of China, conflicting results have been reported as well: a number of studies have found positive spillovers from foreign investment (Buckley et al., 2002; Chuang and Hsu, 2004; Li et al., 2001; Liu et al., 2001; Liu and Wang, 2003; Tian, 2007), though others (Hu and Jefferson, 2002; Hu et al., 2005; Huang, 2004; Liu, 2002) have revealed negative spillover impacts.

Crespon and Fontoura (2007) found that no singular conclusion can be made on the spillover impacts of FDI after an extensive review of the literature on this topic. The nature of FDI impacts is contingent on a number of factors: the absorptive capacity and technology gap between foreign and domestic firms, the characteristics of domestic firms such as their size and export capacity, the characteristics of foreign investments such as their sources of countries, and the trade policy and intellectual property rights protection in the host countries.

Compared to technology transfer and the spillover effects of FDI, in-house R&D is considered less significant for developing countries, since the major task for domestic firms in these countries is to learn from firms in developed countries and to transfer advanced technologies. However, in-house R&D is critical for firms even at this stage, since it helps nurture internal absorptive capabilities and their long-term innovative capability (Bell and Pavitt, 1997; Cohen and Levinthal, 1989). Without such in-house capabilities, firms in developing countries cannot monitor and screen the technologies in the market and they simply do not know which technologies to borrow. Without such capabilities, such firms cannot successfully transfer the technologies from developed countries and they will not be able to achieve technological independence and sustainable development in the long term. Instead they will fall into the vicious cycle of import-transfer again and again. As such, many countries have emphasized indigenous R&D.

Empirically, many studies have found that in-house R&D makes significant contributions to innovations in developing countries. For example, Liu and Wang (2003) found that in-house R&D showed positive and significant impacts on total factor productivity in Chinese industries. In-house R&D also helps domestic firms to capture spillover effects from FDI. However, a couple of recent studies have found that the opposite is true. In their analyses of innovation of Chinese enterprises, Abraham et al. (2006) found that in-house R&D showed negative impacts on total factor productivity, based on a panel of more than 10,000 plant-level records. They also found that in-house absorptive capabilities measured by intangible assets of a firm "seems to increase indeed the incidence of technology spillovers, [though] the impact is negligible in economic terms" (p. 20). In another study based on the recent Chinese economic census data, Sun (2010) found that in-house R&D is negatively associated with TFP in Chinese industries. In this study, we want to examine the relationships between in-house R&D and the narrowly defined innovation, also using the recent economic census data to see whether such relationships are consistent with what have been revealed before.

4. Data and methodology

The data used in this study come from the China Economic Census Yearbook (China State Statistical Bureau, 2006). The census covers all sectors in the secondary and tertiary industries in China and includes a wide range of data. The published data consist of four volumes: the first volume on overall data, the second and third volumes on the secondary industry, and the fourth volume on the tertiary sector. All the data are tabulated by sector and province. Most data are reported at the two-digit sector level while certain data are reported at the three-digit and even four-digit sector levels. The published data also focus on those firms whose annual sales are above 5 million yuan, while only a few selected indicators for smaller firms are reported. As such, we will focus on those "bigger" firms.

Ideally, we would focus on Chinese domestic firms. However, most of the published census information only makes the separate data available at the 2-digit industry level (38 sectors in total), while much detailed data are available for firms where ownerships are not differentiated. To avoid sacrificing too much freedom, we will use the data at the three-digit sector level where data for different ownerships are combined together. We will focus on the 165 sectors in manufacturing. Since some variables are missing from certain sectors, the final analyses will focus on the 144 sectors in manufacturing.

Specifically, the following model is used to examine the relationships between innovation and the various factors:

$$\begin{aligned}\text{Innovation} = {} & \alpha_0+\alpha_1\text{R\&D}+\alpha_2\text{ Assimilation}+\alpha_3\text{ For\_Licensing}\\ & +\alpha_4\text{ Dom\_Licensing}+\alpha_5\text{ For\_Inv}+\alpha_6\text{ Renovation}\\ & +\alpha_7\text{ Export}+\alpha_8\text{ SOE}+\varepsilon \end{aligned} \quad (1)$$

Table 1 gives the definition and measurement for each variable. Innovation is measured by two different variables: patent grants (Patent_Emp) and new product sales (New Products). Patents include all patents that have been granted to the firm. We choose patent grants instead of patent applications because granted patents indicate the higher quality of such innovations, since granted patents are the results of externally scrutinized patent applications. [Thanks to a reviewer who pointed out that the granting of patents includes a step that is outside the control of a firm (e.g., backlogging in patent offices). However, we have no evidence to show that the process is biased

Table 1
Definition of variables.

Name	Measurements	Expected impacts
Dependent variables		
Patent_Emp	Numbers of patent grants per 10,000 employees in a sector	
New products	Percentage of new products sales out of gross output in a sector	
Independent variables		
R&D	Percentage of in-house R&D spending out of gross output put in a sector	+
For_Licensing	Spending on licensing foreign technologies per employee (yuan)	+
Dom_Licensing	Spending on licensing domestic technologies per employee (yuan)	+
Assimilation	Spending earmarked for assimilating/absorbing technologies acquired externally per employee (yuan)	+
Renovation	Spending for technology upgrading and renovation per employee (yuan)	+
Export	Percent of export out of gross sales in a sector (%)	+
SOE	Percent of SOEs out of the total asset in a sector (%)	–
FIEs	Percent of foreign invested enterprises out of total assets in a sector (%)	+

Notes: All variables are in natural logarithm format in the statistical modeling exercise.

towards some firms/sectors than others. As such, patent grants and applications should strongly correlate with each other, with a time lag. Thanks to the same reviewer who pointed out that it might be better to use invention patent grant data instead of overall patents, since domestic firms are more likely to file ‘‘utility models’’ as well as ‘‘design’’ patents than foreign firms, and invention patents are more economically significant. Unfortunately, such data at the three-digit level for the 2000 Census were not reported. It will be interesting to see how the conclusions will change, should we obtain the data in the future.] The dependent variable Patent_Emp takes the ratio between patent grants and total employment in a sector to eliminate the impacts of the size of individual industry. New products, according to the documentation of China Economic Census, refer to ‘‘those products resulting from adopting new technological principles and new designs as well as those with significant improvement in structure, material, processing, etc. over existing products.’’ The dependent variable (New Products) is measured by the ratio between new products sales and total output for a sector.

Internal R&D efforts are represented by two variables: R&D and assimilation, where R&D represents in-house R&D spending and assimilation represents funding specifically earmarked for ‘‘assimilating’’ technologies imported from foreign countries. According to the documentation, examples of ‘‘assimilation’’ spending include funding to cover staff training, salary for people engaged in such activities, supplemental processing technology development, and equipments purchase, among others. Assimilation refers to activities that try to master, apply and duplicate as well as those that aim to improve technologies that are imported from foreign countries (not from domestic agencies, according to the census definition). According to the same documentation, part of the spending on assimilation is also included in R&D expenditure. We expect both in-house R&D and assimilation funding will exert positive impacts on technological innovation.

Two variables measure technology transfer: spending on licensing technologies from foreign countries (For_Licensing) and spending on purchasing domestic technologies (Dom_Licensing). More specifically, such spending includes expenditure on importing product design, processing technologies, blueprints, receipts, patents, etc, as well as expenditure on acquiring key equipments, instruments, prototypes, and others. Given that China is still a developing country, we expect international technology transfer will play a more significant role in industrial innovation than domestic technology transfer.

In Chinese enterprises, technological efforts also include a category so-called technological renovation, which refers to activities that ‘‘apply scientific and technological achievements to various areas (including products, equipments, processes, etc.), including those using advanced technologies to upgrade old technologies, and using advanced process technologies to replace old equipments and processes in order to improve product quality, upgrade processing technologies, reduce energy and raw material consumption, and enhance comprehensive economic efficiency.’’ Such costs are more about improving product quality and processing technologies. As such, they are strongly related to new product development. However, due to the incremental nature of such efforts, we expect that their relationship with patents is not strong.

The presence of foreign invested enterprises (FIEs) in a sector is measured by the share of FIEs in the total equity of each sector and such investments include those from Hong Kong, Marco, Taiwan, as well as those from other countries. We also include Export and SOEs as two control variables, where Export measures the share of export in total sales for a sector (Export), and SOEs measure the share of state-owned enterprises in a sector's total equity. We expect export will be positively associated with industrial innovation while SOEs will be negatively associated with innovation.

With each dependent variable, we run five sets of regressions. The first model includes all the basic independent variables, and the remaining four models include various interactions among in-house R&D efforts, technology transfer, and foreign investments. We want to see whether or not in-house R&D helps to absorb technologies that are transferred from external sources and to capture the spillover effects from foreign investments. All the variables enter the regressions in natural logarithm formats, which have been commonly used by many previous studies. Such models help to capture the potential non-linear relationships between innovation and other variables as well as to reduce the potential problem of heterogeneity.

5. Results

Table 2 compares the innovative performances of enterprises in different ownerships. The data show that enterprises in China (both domestic and foreign invested) in general are not very innovative as measured by outputs such as new products and patents or inputs such as R&D investment and others. Among 276,467 enterprises with sales above five million yuan in 2004, the average number of patents owned by one enterprise was only about 0.11, or ten such enterprises have just one patent. In another measurement, industrial enterprises only have one patent for every 1000 employees. New products are about 10% of their

Table 2
Innovation in enterprises of different ownerships (2004).

Variables		Total	Domestic enterprises	SOEs	FIEs
Outputs (billion yuan)	A	22 232	15 517.8	7022.9	6713.8
%	B	100	69.80	31.59	30.20
Employments (M. employments)	C	93	73.1	19.7	19.9
%	D	100	78.60	21.18	21.40
Firms	E	276,467	219,307	35,597	57,165
Patents	F	30,315	23,734	9244	6581
Patents per firm	G	0.11	0.11	0.26	0.12
Patents per 1000 employees	H	0.33	0.32	0.47	0.33
New product sales (billion yuan)	I	2280.8	1351.2	1043.4	929.1
%	J	10.26	8.71	14.85	13.84
R&D spending (million yuan)	K	110,455	80,504.7	54,132.8	29,950.4
% (K/A)	L	0.50	0.52	0.77	0.45
R&D spending/employment (K/C)	M	1187	1101	2747	1504
Renovation (million yuan)	N	295,560	259,061.9	196,792.0	36,497.7
Renovation/employment (N/C)	O	3178	3543.9	9989.4	1833.1
For_Licensing (million yuan)	P	39,736	21,073.8	24,135.4	18,662.6
For_Licensing/Employment (P/C)	Q	427	288.2	1225.1	937.2
Assimilation (million yuan)	R	6121	4205.4	3161.3	1915.2
Assimilation/employment (R/C)	S	66	57.5	160.5	96.2
Dom_Licensing	T	8248	7323.8	5090.3	924.5
Dom_Licensing/Employment (T/C)	U	89	100.2	258.4	46.4

Notes:

1. Data come from China State Statistical Bureau, (2006), China Economic Census Yearbook (2004).
2. Enterprises include all those with sales above 5 million yuan in 2004.
3. SOEs include enterprises where the state is the sole owner or holds the controlling shares.

total output, and on average, industrial firms contribute about one half percent of their sales to R&D. Such numbers are clearly lower than what is observed in many other countries.

Technological renovation still claims the largest amount of resources among all the different technological efforts while in-house R&D is the second largest spending. On average, firms in China spend 3178 yuan per employee on technological renovation and 1187 yuan per employee on in-house R&D, compared to 427 yuan per employee on licensing technologies from foreign countries, 89 yuan per employee on licensing domestic technologies, and 66 yuan per employee on absorbing externally acquired technologies. Such a picture is similar to what was observed in the mid-1990s. In 1996, Chinese medium and large enterprises (LMEs) spent most resources on technological renovation (3226 yuan per employee), while their spending per employee on in-house R&D, licensing foreign technologies, assimilation and licensing domestic technologies were about 990, 831, 35 and 67 yuan, respectively (Ministry of Science and Technology, various years). Clearly, Chinese enterprises are still very much interested in minor technological upgrading, which could lead to quicker market successes than in-house R&D, which helps build long-term technological competitiveness.

It is interesting to note that not much difference exist between domestic and foreign firms regarding their innovation performance measured by patents, though FIEs seem to be more innovative when measured by new product sales. On innovation inputs, different patterns show up when comparing domestic and foreign enterprises. Chinese domestic firms are slightly more innovative than FIEs when measured by the share of R&D spending in their sales (0.52% versus 0.45%), though the contrary is true when measured by spending per employee: 1504 yuan per employee for FIEs versus 1101 yuan per employee for Chinese domestic enterprises. This indicates that Chinese domestic enterprises are more labor intensive than foreign companies. Compared with foreign enterprises, Chinese domestic enterprises spend much more on technological renovation and licensing technologies from domestic sources, while FIEs spend more on licensing and absorbing technologies from other countries. Such results are not surprising because domestic firms are expected to be engaged in more interactions with domestic technology providers while FIEs will interact more with their foreign parent firms or partners.

What is surprising is that in general, SOEs seem to be more innovative than Chinese domestic enterprises as well as FIEs, and the results are consistent across all the different measurements. Previous studies have found that Chinese SOEs are less innovative than other Chinese and foreign firms. For example, in their study of large and medium enterprises, Jefferson et al. (2003) revealed that new products sales contributed about 20% to total output for SOEs, while such a ratio was about 40% for foreign invested enterprises. In contrast, this study finds that new products take 14.85% of gross output for SOEs, but only 13.84% for FIEs and 8.71% for Chinese domestic enterprises (including SOEs). Jefferson et al. also found that SOEs did not perform as well as FIES or domestic firms of other ownerships when measured by patents, though the R&D investment intensity is not much different among the firms of different ownerships.

However, the results reported here include all firms with output above five million yuan, while Jefferson et al. included only large and medium enterprises. To make the results comparable to Jefferson et al., we also compile the data for large and medium enterprises (Table 3). Table 3 clearly shows that the results for LMEs are significantly different from the results we reported before but are consistent with what Jefferson et al. have found—Chinese LMEs are performing better than foreign firms when measured by patents, though FIEs observe higher shares of new products in their output. This could be because Chinese firms favor utility of invention patents or designs while foreign firms are more interested in invention patents (Sun, 2003). (Thanks to the comments from an anonymous reviewer for this point.) In 2007, among the 586,498 Chinese domestic patent applications, 26.1% belonged to the category of “inventions”, while utilities and design patents accounted for 30.&% and 43.2%, respectively. In comparison, among the 107,419 foreign patent applications in

Table 3
Innovation in large and medium enterprises in China.

Variables		Total	Domestic enterprises	SOES	FIEs
Outputs (billion yuan)	A	13 337	8761	3029	4576
%	B	100	65.69	22.71	34.31
Employments (M. employments)	C	35.1	25.6	10.6	9.5
%	D	100	72.93	30.20	27.07
Firms	E	27,692	18,791	3900	8901
Patents	F	17,988	13,884	2445	4104
Patents per firm	G	0.65	0.74	0.63	0.46
Patents per 1000 employees	H	0.51	0.54	0.23	0.43
New product sales (billion yuan)	I	2042	1189	334	853
%	J	15.3%	13.6	11.0	18.6
R&D spending (million yuan)	K	95,449	69,683	22,757	25,766
% (K/A)	L	0.72	0.80	0.75	0.56
R&D Spending/Employment (K/C)	M	2719	2722	2147	2712
Renovation (million yuan)	N	259,060	229,259	102,891	29,802
Renovation/Employment (N/C)	O	7381	8955	9707	3137
For_Licensing (million yuan)	P	36,795	19,871	7236	16,924
For_Licensing/Employment (P/C)	Q	1048	776	683	1781
Assimilation (million yuan)	R	5397	3729	878	1668
Assimilation/Employment (R/C)	S	154	146	83	176
Dom_Licensing	T	6992	6423	2183	569
Dom_Licensing/Employment (T/C)	U	199	251	206	60

Notes:

1. Data come from China State Statistical Bureau (2006) and China Economic Census Yearbook (2004).
2. Data in this table only include large and medium enterprises as defined by the Chinese Statistical Bureau. There is no uniform definition for large and medium enterprises in China and different criteria are used for different industries. Most often, such criteria include measurements of production capacity, asset, and employment.
3. SOEs in this table include those enterprises where the state owns all the assets.

Table 4
Descriptive statistics and correlation coefficients for the variables.

	Variables	Mean	St. Dev.	A	B	C	D	E	F	G	H	I	J
A	Patents_Emp	6.94	8.01	1									
B	New Products	9.5	8.43	0.48[a]	1								
C	R&D	0.56	0.63	0.50[a]	0.76[a]	1							
D	For_Licensing	503	1147	0.28[a]	0.56[a]	0.54[a]	1						
E	Dom_Licensing	143	334	0.24[a]	0.47[a]	0.51[a]	0.61[a]	1					
F	Assimilation	84	149	0.28[a]	0.47[a]	0.54[a]	0.72[a]	0.69[a]	1				
G	Renovation	3749	6094	0.24[a]	0.53[a]	0.51[a]	0.64[a]	0.73[a]		1			
H	Export	25.37	21.27	0.10	0.07	0.01	−0.21[a]	−0.46[a]	−0.29[a]		1		
I	SOE	14.03	13.87	0.05	0.29[a]	0.27[a]	0.43[a]	0.55[a]	0.46[a]	0.60[a]	−0.45[a]	1	
J	FIEs	20.17	11.68	0.08	−0.08	−0.09	−0.22[a]	−0.42[a]	−0.26[a]	−0.47[a]	0.56[a]	−0.62[a]	1

Notes: Mean and St. Dev. (standard deviation) are calculated based on the original variable measurements, while correlation coefficients are calculated based on the natural logarithm transformations of the original variables.

[a] Indicates correlation coefficients significant at the level of 0.05.

China, 85.7% belonged to the category of inventions while utilities and design patents together only accounted for less than 15%. Chinese LMEs are spending more on in-house R&D and technology upgrading, and interact more with domestic technology markets, while foreign LMEs are spending more on licensing and absorbing technologies from foreign countries. Among large and medium enterprises, SOEs demonstrate the *worst* innovative performance; they show the lowest in many measurements: patents/employee ratio, share of new products in total output, R&D spending per employee, and spending on licensing foreign technologies and assimilation. Nevertheless, SOEs' spending on technology upgrading is the highest among the different ownerships, and their performance measured by in-house R&D spending intensity and interaction with domestic technology providers is better than FIEs, though worse than domestic enterprises in general. Such results clearly show that the Chinese government's strategy of "grasping the big ones and let the small enterprises go" has not been very successful when measured by technological innovation. The large and medium SOEs, which are supposed to be the primary forces to implement the Chinese government's innovation strategy, have become the least innovative element of China's economy. It is time for the Chinese government to reorient its efforts to help non-government owned enterprises to implement its innovation strategy.

Table 4 shows the correlation coefficients among the variables and innovation (patent and new product sales) are significantly correlated with in-house R&D effort and technology transfer, though its relationship with export, SOEs, and FIEs are not significant. Such results suggest that both in-house R&D and technology transfer are important sources of innovation in China, though the spillover effects of foreign investments on technological innovation are not significant yet.

The results from the regression analyses are reported in Tables 5 and 6 with patents and new products as the dependent variables, respectively. From the different analyses, a few consistent results can be observed. First, in-house R&D shows the strongest impact

Table 5
Results of regression analyses I: with patents as the dependent variable.

	Model 1		Model 2		Model 3		Model 4		Model 5	
	B	St. Error	B	St. Error	B	St. Error	B	St. Error	B	St. Error
Dependent variable: Patents_Emp										
Independent variables:										
Constant	−1.311	1.381	−1.175	1.385	−1.195	1.397	−0.044	1.503	−1.249	1.387
R&D	0.587***	0.114	0.466***	0.159	0.700***	0.215	0.642***	0.116	0.818**	0.381
For_Licensing	−0.058	0.076	−0.009	0.088	−0.062	0.077	−0.209**	0.106	−0.058	0.077
Dom_Licensing	−0.034	0.110	−0.040	0.110	−0.070	0.125	−0.059	0.110	−0.036	0.111
Assimilation	0.012	0.097	0.014	0.096	0.010	0.097	−0.163	0.129	0.027	0.100
Renovation	0.311**	0.152	0.297*	0.153	0.315**	0.153	0.255*	0.153	0.313**	0.153
Export	−0.021	0.123	−0.046	0.125	−0.008	0.125	−0.048	0.123	−0.021	0.123
SOE	−0.033	0.153	−0.075	0.158	−0.026	0.154	−0.039	0.152	−0.021	0.155
FIEs	0.407**	0.195	0.382*	0.196	0.401*	0.196	0.370*	0.194	0.353*	0.213
R&D*For_Licensing			0.036	0.032						
R&D*Dom_Licensing					−0.033	0.054				
Assimilation*For_Licensing							0.045**	0.022		
R&D*FIEs									−0.074	0.117
# of observations	141		141		141		141		141	
R^2	0.316		0.322		0.318		0.336		0.318	
Adj. R^2	0.274		0.276		0.271		0.291		0.271	

* Significant at the level of 0.10.
** Significant at the level of 0.05.
*** Significant at the level of 0.01.

Table 6
Results of regression analyses II: with new products as the dependent variable.

	Model 1		Model 2		Model 3		Model 4		Model 5	
	B	St. Error	B	St. Error	B	St. Error	B	St. Error	B	St. Error
Dependent variable: Patents_Emp										
Independent variables:										
Constant	9.707	0.565	0.565	0.549	9.499	0.562	10.488	0.600	9.808	0.560
R&D	0.531***	0.044	0.044***	0.063	0.349***	0.087	0.561***	0.044	0.856***	0.154
For_Licensing	0.070**	0.031	0.031***	0.035	0.077**	0.031	−0.025	0.043	0.070**	0.031
Dom_Licensing	0.062	0.044	0.044	0.042	0.122	0.050	0.049	0.042	0.057	0.043
Assimilation	−0.023	0.039	0.039	0.038	−0.018	0.038	−0.133**	0.051	−0.004	0.040
Renovation	0.123**	0.062	0.062**	0.061	0.113*	0.061	0.085	0.061	0.128**	0.061
Export	0.196***	0.047	0.047***	0.046	0.182***	0.047	0.181***	0.046	0.194***	0.047
SOE	−0.049	0.062	0.062	0.062	−0.055	0.061	−0.050	0.060	−0.035	0.061
FIEs	0.037	0.078	0.078	0.076	0.046	0.077	0.015	0.076	−0.038	0.084
R&D*For_Licensing			0.565***	0.013						
R&D*Dom_Licensing					0.051**	0.021				
Assimilation*For_Licensing							0.029***	0.009		
R&D*FIEs									−0.103**	
# of Observations	141		141		141		141		141	
R^2	0.748		0.765		0.758		0.765		0.756	
Adj. R^2	0.733		0.749		0.742		0.750		0.740	

* Significant at the level of 0.10.
** Significant at the level of 0.05.
*** Significant at the level of 0.01.

on innovation. One percentage increase of in-house R&D spending led to growth in patent grants per employee and the share of new product in total sales in a sector by 0.59% and 0.53%, respectively. In-house R&D also enhances the impacts of technology transfer in general, though *unexpectedly*, it contributes *negatively* to capture the spillover impact of FIEs. However, the other measurement of in-house R&D effort, spending on assimilating foreign technologies, does *not* make significant contributions to either patents or new products, though it does enhance the effectiveness of technology transfer from foreign countries.

Second, technology transfer spending (either domestic or foreign) does not lead to more patents. Indeed, they are negatively associated with patents, though statistically insignificant. Technology transfer from foreign countries does contribute positively (though very weakly) to new product sales, though domestic technology transfer is not significant in the different models. Such results indicate that licensing foreign or domestic technologies does not lend significant help for improving Chinese enterprises' original innovative capability, though such spending offers them a quick path to develop new products for the markets in the short term. The negative coefficient between spending on technology transfer and patent grants (Table 4) suggests that technology transfer competes for resources with in-house R&D, and thus reduces the chance to develop more proprietary intellectual property, though absorptive capabilities are closely related to development capabilities, and the boundary between these two is hard to tell sometimes.

Third, the spillover effects of foreign investments on patents are *positive*, *strong*, *significant*, and *consistent*, though its impact on new products sales is *insignificant* albeit *positive*. The results are comforting for Chinese government officials, since foreign investments did demonstrate positive spillover effects on Chinese domestic enterprises' technology development, due to various channels discussed before. On the other hand, the results revealed that Chinese domestic enterprises have failed to capitalize on such technological spillover effects from FIEs and translate such positive technological impacts to economic performance in the market. Such an observation is consistent with the negative spillover effects of FIEs on the total factor productivity of Chinese domestic enterprises recently revealed by Abraham and Sun. This clearly demonstrates that industrial competitiveness is more than technological capability and innovation, and there still exists a significant gap between technological capability and market success in Chinese enterprises. How to effectively integrate R&D efforts with production and marketing, among other functions, is critical for Chinese enterprises to achieve success.

Fourth, spending on technological upgrading or renovation is positively associated with both patent development and new product sales. It is expected for such activities to contribute positively to new product sales, since they often occur because of the need to manufacture new products. However, how such activities could help enhance firms' original innovative capability is unclear. Such efforts help build firms' absorptive capabilities when firms implement such technologies and Chinese enterprises indeed also learn new knowledge as they adopt foreign technologies.

However, export did not exert significant impact on patent development. Such results suggest that Chinese enterprises are not competing on the bases of original innovation in the international market. However, export contributes positively to more new product sales in China. The different impacts of export on patents and new product development indicate that export does force Chinese enterprises to develop new products, though such new products do not lead to (or result from) new patents. On the one hand, it indicates the weakness of patents as innovation; on the other hand, it also indicates that most of such new products are not radically "new", but only involve minor improvements due to the loose definition of new products in the Chinese census.

Finally, the impact of SOEs on innovation is very weak and insignificant. In most cases, the signs of the variable in the models are negative after controlling the impacts of other factors. Such results simply confirm the observations by many that Chinese SOEs are less efficient than other parts of the economy, though their overall innovative performance has improved significantly.

6. Conclusions and discussion

This study reveals that industrial enterprises in China are not very innovative in general when measured by patents and new products, though Chinese domestic enterprises are more innovative than foreign invested enterprises (Jefferson et al., 2003). SOEs remain the least innovative elements of Chinese economy. This study also confirms the findings from previous studies that Chinese enterprises are still much more interested in technological upgrading than in-house R&D, or licensing foreign/domestic technologies (Sun, 2002b). In addition, this study finds that Chinese domestic enterprises are more actively engaged in the domestic technology market while FIEs are more actively interacting with foreign technology markets.

The study demonstrates that in-house R&D has become the most important source of technological innovation for industrial enterprises in China. In-house R&D helps build firms' innovative capability and long-term competitiveness. In-house R&D also enhances the effectiveness of technology transfer (Bell and Pavitt, 1997; Cohen and Levinthal, 1989). Compared to the importance of in-house R&D, technologies transferred from external sources failed to explain the sectoral differences of innovative performance in China. Furthermore, no significant spillover effects of foreign investments on technological innovation are observed. Such results are contrary to many previous studies on this topic (Tian, 2007; Chuang and Hsu, 2004; Buckley et al., 2002; Li et al., 2001; Liu et al., 2001; Liu and Wang, 2003).

Such results on the one hand confirm the observation that advanced technologies cannot really be imported from foreign countries but can only be developed internally. The results lend further support to the recent drive for indigenous innovation initiated by the Chinese government. On the other hand, the insignificance of domestic technology market in the models suggests that industrial firms and the S&T sector in China have not been well integrated, and the linkages between firms and universities/R&D institutes are still very weak (Baark, 1992; Liu and White, 2001; Simon and Goldman, 1989; Sun, 2002a). Put in another way, the Chinese S&T sector, including universities and R&D laboratories, has not made significant contributions to industrial technology, despite the recent surge in research funding. This raises the question of whether or not the recently so-called S&T take-off in China has been economically efficient and effective.

The strong and positive impacts of in-house R&D on industrial innovation and the negligible spillovers from FIEs are in line with findings from the majority of studies, though contrary to what have been reported recently. For instance, Sun (2010) and Abraham et al. (2006) have revealed that in-house R&D is *negatively* related to technological innovation while the spillover effects from foreign investment are positive and strong in China. We argue that such differences primarily result from how technological innovation is measured. In this study, we use patents and new products while Sun (2010) and Abraham et al. (2006) used total factor productivity in their studies. Patents and new products are direct measurements of the narrowly defined technological innovation, while TFP measures the overall efficiency of resources usage. As mentioned before, TFP growth can result from more sources than patents and new products. We argue that in-house R&D is more directly related to patents and new products, and in-house R&D is just one source of TFP. The positive relationship between in-house R&D and patents/new products and its negative relationship with TFP suggest that Chinese enterprises have not well integrated their technological efforts with other functions (production, marketing, or sales) within a firm. Chinese enterprises have failed to capitalize on some of their technological strengths, though such strengths rarely exist. Therefore, results from this study show the needs to further reform the internal R&D organizations within Chinese enterprises. This finding is significant because the Chinese government has aimed to build an industry-firm centered innovation system. Without appropriate internal R&D organization, Chinese firms will not be able to achieve sustainable technological/market success.

Similarly, the spillover effects of foreign investment can result in TFP growth among domestic enterprises, though not necessarily in narrowly defined technological innovation. This indicates that *technological* spillovers from FIEs are weak though spillovers can occur in other forms and through other channels such as labor movement, adoption of new management practices, or export (Tian, 2007; Chuang and Hsu, 2004; Buckley et al., 2002; Li et al., 2001; Liu et al., 2001; Liu and Wang, 2003).

In conclusion, our study offers new evidence to show that in-house R&D is of critical importance for Chinese industrial firms to achieve technological innovativeness and build long-term market competitiveness. The results also suggest that industrial firms have not been able to capitalize on China's recent S&T take-off. It is imperative for China to further reform its national innovation system so that industries and the S&T sector are better connected with each other. It is also critical for Chinese firms to further reform their internal organization to better link technical efforts with production. Otherwise, the recent S&T take-off will be an "S&T Great Leap Forward" (The "Great Leap Forward" refers to the period between 1958 and 1960, during which the Chinese government tried to transform China from a primarily agrarian economy to a modern, industrialized communist economy. It is considered a major economic disaster in Chinese history.), not necessarily leading to the market success as hoped.

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