What matters for industrial innovation in China: R&D, technology transfer or spillover impacts from foreign investment?

Yifei Sun

Department of Geography,
California State University, Northridge,
Northridge, CA 91330-8249, USA
Fax: +1 818 677 2723
E-mail: yifei.sun@csun.edu

Abstract: This study examines the relationship between industrial output and in-house R&D, technology transfer and spillovers from foreign investment in China using the most recent economic census data (2004) published by the Chinese State Statistical Bureau in 2006. It reveals that none of the three factors – in-house R&D, technology transfer and spillovers from foreign investment – can effectively explain the sectoral differences of output. The study also reveals that capital and state-owned enterprises (SOEs) show consistent and significant impacts on output, where capital demonstrates positive impacts while SOEs show negative impacts. Also interesting is that the impact of export on industrial differences of output is *insignificant*, though still positive. Such results cast serious doubts on the sustainability of China's strategy of relying on foreign investment, export and its recent innovation drive.

Keywords: FDI; foreign direct investment; R&D; research and development; technology transfer; spillovers; export; SOEs; state-owned enterprises; China; systems perspective.

Reference to this paper should be made as follows: Sun, Y. (2010) 'What matters for industrial innovation in China: R&D, technology transfer or spillover impacts from foreign investment?', *Int. J. Business and Systems Research*, Vol. 4, Nos. 5/6, pp.621–647.

Biographical notes: Yifei Sun is an Associate Professor in the Department of Geography, California State University, Northridge. His research interests fall within economic geography. Particularly, he is interested in technology, innovation and urban and economic development in China. His research has been funded by the US National Science Foundation (Project # BCS-0552265). Recently, he completed a project on foreign research and development in China. Currently, he is working on a project on examining technological upgrading in China's three major city-regions: Beijing, Shanghai-Suzhou and Shenzhen-Dongguan. His co-edited book: *Global R&D in China* was published by Routledge in 2008.

1 Introduction

The importance of foreign direct investment (FDI) for developing countries' economic development has been widely recognised. In 2005, developing countries attracted US$320 billion or about 34.9% of the world's total FDI (UNCTAD, 2007). FDI not only provides capital and employment for host countries, but also brings more advanced technologies and management practices to their foreign affiliates. More importantly, it is hoped that FDI can help domestic firms in developing countries to master such technologies and practices through so-called spillovers so that sustainable development can be achieved in the long term. It is based on such hopes that developing countries are engaged in fierce competition for foreign investment through a variety of incentives and policy tools. However, a number of recent studies have questioned such a strategy. These studies have found *negative* spillover impacts, instead of positive ones, of FDI on domestic firms in developing countries (Aitken and Harrison, 1999; Djankov and Hoekman, 2000; Haddad and Harrison, 1993). It is argued that the crowding-out impact of FDI could be stronger than the assumed positive spillovers from FDI in many cases. As such, many have recommended a more critical assessment of FDI's roles in the economic development of developing countries.

China has been very successful in attracting FDI, which has made great contribution to its astounding economic growth since the late 1970s. It has become the largest recipient of FDI among all developing countries. In 2005, China attracted $72.4 billion and accumulated FDI (stock) in China has reached $317 billion (UNCTAD, 2007). 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, various years). While some have hailed China as the 'model' of utilising FDI, others have started questioning this strategy (Lo, 2006). Empirically, mixed results have been found. For example, Hu and Jefferson (2002) and Huang (2004) have found negative impacts of FDI on China's domestic firms while Tian (2007) and Chuang and Hsu (2004) have found positive impacts. Some scholars have argued that China has sacrificed too much its domestic firms in favour of FDI and such a strategy is unsustainable; as costs have risen, the foot-loose FDI may move to other less expensive countries (Huang, 2005). Scholars and government officials in China have argued and realised that the most advanced technologies cannot be obtained from foreign companies and such technologies have to be learned and developed by domestic firms and other agencies (China State Statistical Bureau, 2006).

Consequently, China has initiated a new national innovation drive recently. In early 2006, it published the *Guidelines for the National Medium- and Long-Term Science and Technology Development Program (2006–2020)*. In this programme, the Chinese government emphasises the strategic role of indigenous innovation[1] (*zizhu Chuangxin*), and proposes a number of measures to become an innovation-oriented country by 2020. Indeed, one can see that China has strived and struggled in its science and technology (S&T) efforts. China has not been very successful in this aspect in general, though a few successful cases have been reported. Prominent examples include Datang Telecom Technology Co., Founder, Huawei Technology Corporation (Huawei), Lenovo, Zhongxin Technology Corporation (ZTE), etc. (Fan, 2006a,b; Fan and Watanabe, 2006; Gao et al., 2006, 2007; Lu, 2000). In recent years, the Chinese government and businesses have increased their S&T investment greatly. For example, 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 1.44% in 2004.[2] China plans to increase this ratio to 2.5% by 2020, similar to the current levels observed in many developed countries. This has led some to claim that an S&T take off has occurred in China (Gao and Jefferson, 2007). However, only a few studies have examined whether or not such efforts have paid off and made significant contributions to China's economy (Gao and Jefferson, 2007; Hu and Jefferson, 2004; Hu et al., 2005; Jefferson et al., 2003; Liu and Buck, 2007; Liu and Wang, 2003; Lo, 2006; Sun, 2002b). We argue that without proper reforms in its national innovation system (NIS), such tremendous increase in R&D investment may not be necessarily translated into economic efficiency.

In this study, I choose an eclectic approach, pull the above two threads together, and examine the roles of both in-house R&D and FDI in China's industrial innovation using the most recently published economic census data. Meanwhile, I also incorporate technology transfer into the framework, since the importance of technology transfer for developing countries has been generally accepted. I find that capital and state-owned enterprises (SOEs) are the most important factors that can effectively explain the sectoral differences of technical efficiency in China. Such a finding is consistent among the different specifications of the models. However, none of the variables related to technological efforts show significant impact on sectoral differences of technical efficiency in China. In particular, in-house R&D shows *negative* impact on output. Furthermore, neither export nor foreign investment can effectively explain the sectoral differences of economic efficiency.

Such results demonstrate that China's current economic growth still largely relies on capital input, not on technological innovation, and the results also cast doubts on the effectiveness of China's current drive on indigenous innovation. In addition, serious questions are raised about China's strategy of continuing heavy reliance on export and foreign investment. Clearly, such findings have critical implications for Chinese government and other developing countries regarding their strategies on utilising FDI, encouraging export and their efforts of promoting domestic innovation.

What remains in this paper is organised as follows. Section 2 provides a brief background on FDI and China's recent innovation drive. Section 3 reviews relevant literature while Sector 4 describes the data and methodology. Sector 5 reports the analyses results and Section 6 concludes the study and discusses the implications.

2 FDI and China's innovation drive

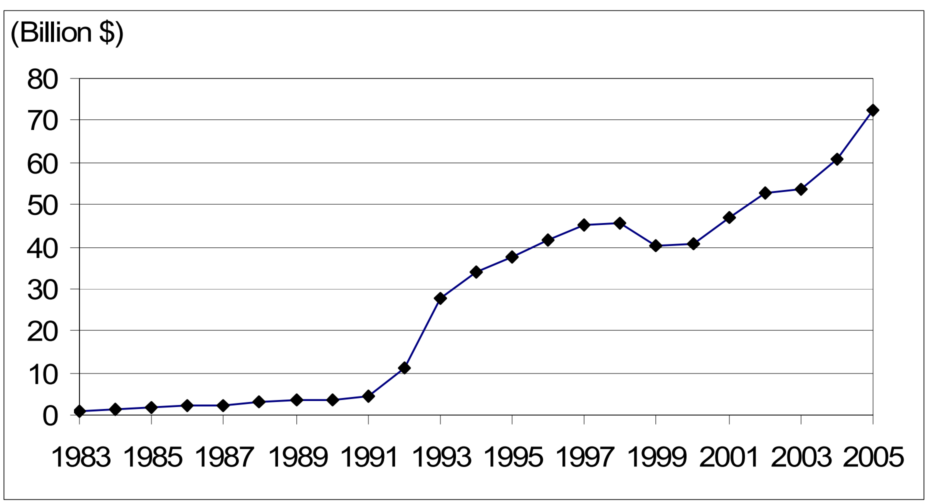
2.1 FDI in China

China opened its door to foreign investment in late 1970s. In 1979, the National People's Congress passed the *Equity Joint Venture Law* and allowed foreign investment. Since then, three stages can be identified (Figure 1). The time from 1979 to 1991 was the first stage, during which the institutional foundation for attracting foreign investments was laid down. In 1980, four Special Economic Zones (Shenzhen, Zhuhai, Shantou and Xiamen) were created and were granted more economic autonomy. In 1984, China decided to further open 14 coastal cities to foreign investors. In 1985, China further opened its Pearl River delta, the Yangtze River delta and Xiamen–Zhangzhou–Fuzhou delta. In 1988, the open area was expanded to include 153 cities and counties in the coastal provinces. In this period, China witnessed steady growth of foreign investment from $1 billon in 1983 to $4.3 billion in 1991. The second period lasted from 1992 to

2000. In 1992, Deng Xiaoping had his renowned southern China tour and called for deepened reform and further openness. Consequently, China quickened its pace of attracting foreign investment and this resulted in immediate and drastic growth of FDI due to the increased confidence of foreign investors in China. In the single year of 1992, FDI more than doubled, growing from $4.4 billion in 1991 to more than $11 billion. By 2000, annual FDI flow to China reached $40 billion a year. In 2001, China joined the World Trade Organization, and it marked the beginning of the third stage in China's history of using foreign investment. Due to further increased confidence in China, FDI experienced faster growth again. In 2005, China attracted more than 70 billion FDI.

FDI has made great contribution to China's economic growth. According to the economic census (2004), foreign invested companies provide 11.1% of China's employment, 30.2% of its industrial revenues and more than 70% of China's export (Table 1). Clearly, the majority of foreign investments are using China as the export platform; they take advantage of China's cheap labour and land, as well as other strengths. There exists a huge disparity between the share of foreign invested enterprises in China's export and their share in employment. This clearly demonstrates that foreign invested companies are still marginally engaged in China's domestic market. As such, it may limit two important channels for the spillovers from foreign invested companies to China's domestic companies: competition between foreign invested firms and Chinese domestic firms in China's domestic market and the limited employment mobility between them. This raises the question where or not the spillover impacts of foreign invested firms on China's domestic companies are significant.

Figure 1 Foreign investment in China, 1983–2005 (see online version for colours)



Source: China State Statistical Bureau (various years).

Table 1 Contributions of FDI to China's economy, 2004

	Total	*%*	*Domestic firms*	*%*	*FHKMT*	*%*	*HKMT*	*%*	*FIEs*	*%*
Employment (million persons)	215	100	191	88.9	24	11.1	12	5.6	12	5.5
Total asset (billion yuan)	96,737	100	86,325	89.2	10,411	10.8	4,235	4.4	6,176	6.4
Income (billion yuan)	44,098	100	35,421	80.3	8,677	19.7	3,099	7.0	5,579	12.7
Industrial export (billion yuan)	4,048	100	1,150	28.4	2,898	71.6	1,032	25.5	1,867	46.1
Industrial revenues (billion Yuan)	21,769	100	15,185	69.8	6,584	30.2	2,385	11.0	4,199	19.3

Note: Financial data in current price (2004), HKMT: Hong Kong, Marco and Taiwan invested firms; FIEs: non-HKMT invested foreign firms; FHKMT: all foreign invested firms including HKMT and FIEs.

Source: Data come from China State Statistics Bureau (2006) *China Economic Census Yearbook* (2004).

2.2 China's national innovation system

China has long realised the importance of S&T and has strived to build its NIS since its founding in 1949. Its NIS has experienced two major periods: the pre- and the post-reform periods (Sun, 2002b). Two features characterised China's NIS in the first era. To begin with, development of military technologies was separated from civilian technologies. Second, there was a clear division of labour (separation) among industries, governmental laboratories and universities. Industrial enterprises were centres of production; governmental laboratories focused on R&D and universities were the training centres with a few exceptions. Governmental laboratories were the major agencies directly performing R&D. Little spontaneous interaction occurred among industries, universities and governmental laboratories. During this period, the state was the driving force of innovation as well as the economy. Governments, particularly the central government, funded and controlled all R&D activities. Innovation was operated through a top–down approach, centred on development of strategic weapons. Such an institutional arrangement explained why China was relatively successful in developing weapons for military purposes, while industrial technologies were not well developed.

Reforms of China's NIS are affected by its overall gradualist approach of reforms, particularly economic reforms. Earlier efforts of reforming China's NIS in the 1980s were characterised by a piecemeal approach and emphasised a strategy of focusing on technology transfer: restructuring the governmental laboratories to improve their efficiency, enhancing their linkages with industries and creating the technology markets so that innovations can be transferred to production smoothly. Suttmeier (2002) characterises this as an S&T strategy.

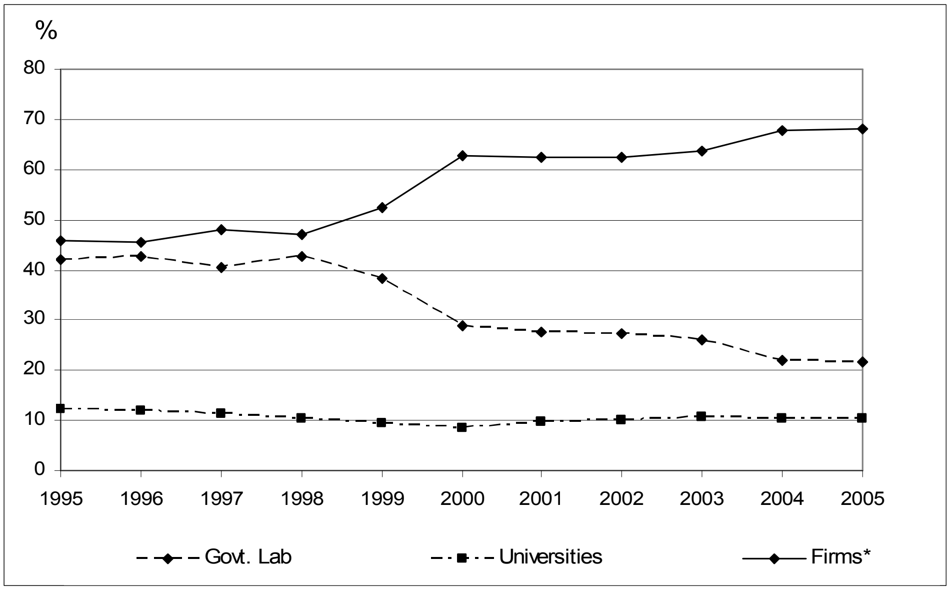
Reforms in the 1990s were characterised by a shift from the earlier technology transfer approach to an innovation approach (Suttmeier, 2002), where enterprises are considered to be the centre of industrial technological development. Such a strategy clearly denounces the separation of R&D from industrial 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. This is the first time that Chinese government documents specified this point, which signalled a clear shift from the previous approaches emphasising the division of labour between governmental laboratories and industrial enterprises and focusing on the supply side of innovation in governmental laboratories (Yu, 1999). Such an approach was further emphasised in 1995 when the central government held the National Science and Technology Conference in Beijing. The 1997 Asian financial crisis made the Chinese government to realise the strategic importance of S&T in economic development. In 1999, the Chinese central government held the National Technological Innovation Conference in Beijing and made an explicit call for the creation of a NIS, recognising the intricate relationships among reforms in economy, S&T, education and innovation. The importance of industrial R&D was further emphasised by these programmes. Indeed, by 2005, industrial firms' R&D spending is about 70% of China's total R&D expenditure (Figure 2).

China has witnessed tremendous growth of resources devoted to S&T development. China's total S&T expenditure expanded from 38.9 billion yuan in 1991 to 483 billion yuan in 2005, governmental S&T budgetary spending grew from 16.1 billion yuan to 127 billion yuan and R&D investment rose from 34.9 billion yuan in 1995 to 236 billion yuan in 2005 (Figure 3). R&D spending was about 0.6% of its GDP in 1995 and by 2005 it grew to 1.34% (Figure 4). Measured by outputs, similar drastic growth has been observed. Chinese domestic patent applications grew from 69,535 in 1995 to 383,157 in 2005; the publications included by Science Citation Index, Index to Science and Technical Proceeding and Engineering Index jumped up from 26,395 in 1995 to 153,000 in 2005. China has become the fourth largest country with publications included in these citation indices, right after the USA, UK and Japan.

In early 2006, the central government published its *Guidelines for National Medium- and Long-Term S&T Program* (2006–2020). The guiding principles for S&T work over the next 15 years are, "Innovate independently, achieve development in selected areas by leaps and bounds, support development and guide the future". According to this document, "innovate independently means proceeding from strengthening the country's innovative capabilities and steeping up the efforts at original innovation, integrated innovation, importation, absorption, assimilation, and re-innovation" (The Levine Institute, 2006, p.93). The Chinese leadership clearly recognised that

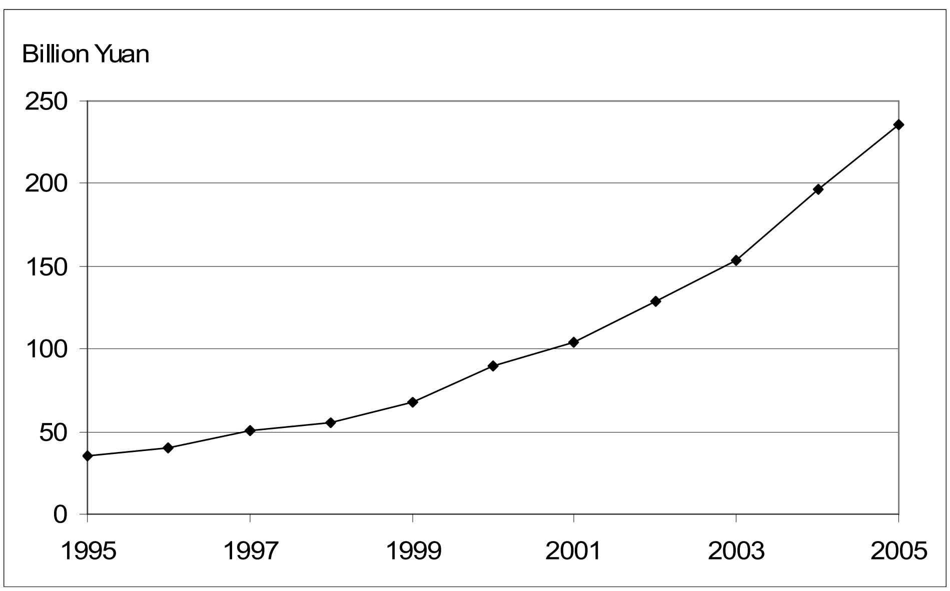
> "bringing in technology without paying attention to absorption, assimilation, and re-innovation will surely weaken our independent R&D capabilities and widen the gap with advanced international standards. Facts tell us that we cannot buy true core technologies in key fields that affect the life hood of the national economy and national security. To gain leverage in fierce international competition, China must improve its independent innovative capabilities, own a number of proprietary intellectual property rights, and groom a number of internationally competitive enterprises in certain important fields." (The Levine Institute, 2006)

Figure 2 R&D performed by different agents in China, 1995–2005



Source: Ministry of Science and Technology (various years).

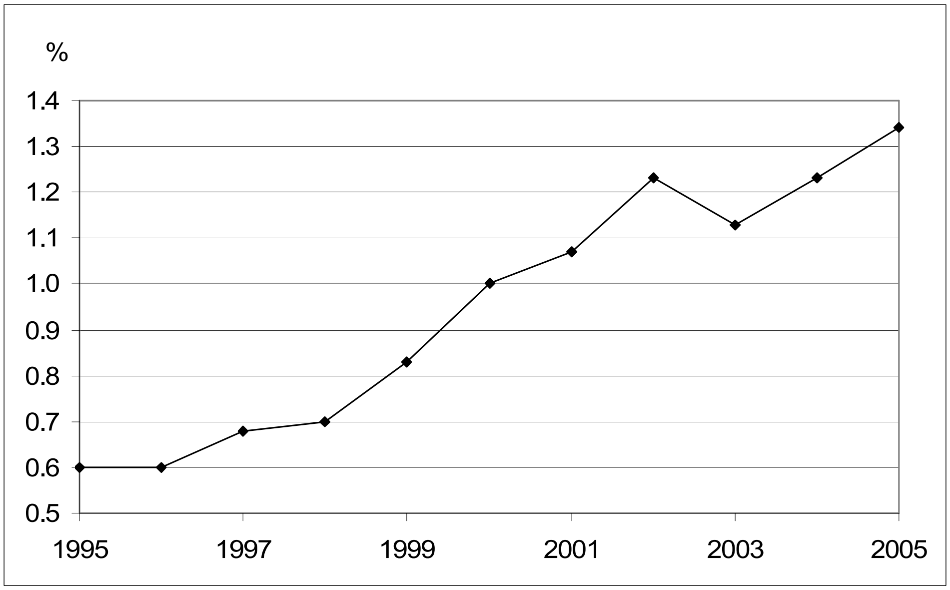
Figure 3 China's R&D spending, 1995–2005



Note: The figure shows the ratio of spending on assimilation and licensing foreign technologies among China's large and medium enterprises.

Source: Ministry of Science and Technology (various years).

Figure 4 China's R&D spending over its GDP, 1995–2005



The guideline gives details on the specific goals; it aims to join the ranks of innovative countries so that the solid foundation is laid down for becoming a world S&T powerhouse by the middle of this century. It aims to increase R&D investment from its current level to 2.5% of its GDP in 2020. This has led some scholars to suggest that China is experiencing an S&T take off (Gao and Jefferson, 2007).

However, progress in S&T is one issue, while whether or not S&T has made significant contribution to economic development is another one. As pointed out before, the Chinese NIS has been plagued with many problems due to the legacies from the planned economy. Particularly, many have argued that Chinese firms are largely reliant on imported technologies, while they 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 economic development? Given that China is still a developing country and many areas are short of resources, these are critical questions to ask. Unfortunately, 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; Sun, 2002a,b). This study wants to reexamine the issue in light of the recent surge of R&D investment in China.

3 Literature review

This section will provide a brief review on two major issues: the spillover impacts of FDI on domestic firms in host countries and the role of R&D in economic development in China.

3.1 Spillovers from foreign investment

The spillover impact refers to externalities for domestic firms due to the presence of foreign invested firms. Among the literature on foreign investments, it is generally accepted that foreign firms need to possess proprietary advantages in order to overcome the challenges of operating in a foreign market, where domestic firms are advantaged due to their familiarity with the local market, institution and culture (Dunning, 1988). Foreign firms' proprietary advantages can come from a variety of sources: product, process and distribution technology, as well as management and marketing skills. However, some of these advantages may not been fully internalised by their foreign affiliates, but can spillover to domestic firms through various channels: *demonstration/imitation*, *labour movement*, *exports*, *competition* and *backward and forward linkages* with domestic firms (Crespo and Fontoura, 2007).

The demonstration impact of foreign invested firms is considered the most evident spillover channel. When foreign firms introduce a new product, domestic firms can follow-up and become the 'copycats'. This helps to reduce the uncertainties associated with introducing new products to a market. Domestic firms can also learn the management practices and marketing strategies from their foreign competitors as well.

The labour mobility between foreign firms and domestic firms is the second channel for spillovers. When domestic firms hire workers who had working experiences with foreign firms, they can learn the management practices and technologies and apply them in their own operations. Of course, the negative impact could also be expected, since foreign companies usually can offer better salaries to their workers, thus attracting more experienced and high-quality workers from domestic firms.

Domestic enterprises can also get access to foreign market due to their connections with foreign firms. Foreign markets are more competitive in general. It is very difficult for domestic enterprises to start export, since they do not know how to obtain access to international distribution networks and have little understanding of the unique demands in foreign markets. The presence of foreign firms could give domestic firms new knowledge in this area.

The increased competition in domestic market is another channel that domestic firms can benefit from the presence of foreign firms. When foreign firms enter the domestic markets, they often bring in new technologies, making the domestic market much more competitive. To survive, domestic firms have to step up their own efforts through developing and improving their own technologies. Of course, this could also lead to the 'crowding-out' effect, where domestic firms are simply forced out of the market due to the large gap between foreign firms and domestic firms (Aitken and Harrison, 1999). Still, if foreign invested enterprises are primarily engaged in export, their competition impact may be limited for domestic firms, since FDI and domestic firms operate in different markets.

Finally, domestic firms can benefit from their engagement in the global value chain of multinational corporations. Domestic firms could become the suppliers of foreign firms (backward linkages) or consumers of intermediate products from foreign invested enterprises (forward linkages). Through backward linkages with foreign firms, domestic firms may receive direct guidance from their customers and learn from them on many issues from product development, process technology improvement, quality control, etc. (Humphrey and Schmitz, 2002; Lall, 1980; Schmitz, 2004). When using intermediate products from foreign companies, domestic companies may be able to improve their product quality and process technologies. Consequently, domestic firms will benefit from such direct market linkages with foreign invested firms.

Empirically, many studies have examined the possible spillover impacts of foreign firm since Caves' (1974) pioneer study on the spillover impacts of foreign firms in Australia (Table 2). His study reveals positive spillover impacts. Following Caves' effort, a few other scholars have examined the issues in other countries, including Globerman's (1979) study on Canada, Blomstrom and Persson (1983) and Blomstrom (1986) study on Mexico and Haddad and Harrison (1993) study on Morocco. Such studies have largely confirmed the existence of positive spillovers from foreign investment, though the study by Haddad and Harrison is an exception and it revealed negative impact of foreign investment on domestic firms in Morocco. Interest in this issue has experienced significant growth since the publication of Aitken and Harrison's study (1999) which found negative impact of foreign investment on domestic enterprises in Venezuela. Negative impacts of foreign investments have been found in other cases as well, and examples include Djankov and Hoekman (2000) on Czech Rep. and Kathuria (2000) on India. Studies have found different results, though they examine the issue in the same country. For example, in the case of China, a number of studies have found positive spillovers from foreign investment (Buckley et al., 2002; Chuang and Hsu, 2004; Li et al., 2001; Liu and Wang, 2003; Liu et al., 2001; Tian, 2007). However, other studies (Hu and Jefferson, 2002; Hu et al., 2005; Huang, 2004; Liu, 2002) have revealed negative spillover impacts.

Table 2 A sample of the literature on spillovers of foreign investment on domestic firms

Reference	*Country*	*Year*	*Data*	*Unit*	*FDI presence*	*Result*
Caves (1974)	Australia	1966	CS	Industry	Employment	+
Globerman (1979)	Canada	1972	CS	Industry	Output	+
Blomstrom and Persson (1983)	Mexico	1970	CS	Industry	Employment	+
Blomstrom (1986)	Mexico	1970/1975	CS	Industry	Employment	+
Haddad and Harrison (1993)	Morocco	1985–1989	Panel	Firm industry	Assets	–
Aitken and Harrison (1999)	Venezuela	1976–1989	Panel	Firm	Combined	–
Djankov and Hoekman (2000)	Czech Rep.	1993–1996	Panel	Firm	Output	–
Kathuria (2000)	India	1976–1989	Panel	Firm	Output	–
Liu et al. (2001)	China	1996/1997	CS	Industry	Asset	+
Liu (2002)	China	1993–1998	CS	Industry	Asset	–
Li. et al. (2001)	China	1995	CS	Industry	Assets/employment	+
Buckley et al. (2002)	China	1995	CS	Industry	Assets/employment	+
Liu (2002)	China	1993–1998	Panel	Firm	Combined	+
Hu and Jefferson (2002)	China	1995–1999	Panel	Firm	Combined	–
Liu and Wang (2003)	China	1995	CS	Sector	Asset	+

Table 2 A sample of the literature on spillovers of foreign investment on domestic firms (conitued)

Reference	*Country*	*Year*	*Data*	*Unit*	*FDI presence*	*Result*
Chuang and Hsu (2004)	China	1995	CS	Firm	Employment	+
Huang (2004)	China	1993/1994/ 1997	CS	Industry	Employment	–
Abraham et al. (2006)	China	2002–2004	Panel	Firm	Output	Mixed
Liu et al. (2007)	China	1997–2002	Panel	Industry	Foreign industrial R&D	+
Tian (2007)	China	1996–1999	Panel	Firm	Assets/employment/ sales	+

Note: Based on Tian (2007) and personal search.

Such conflicting results have led scholars to explore the question of why in certain cases positive impacts are found, while the opposites are found in other cases. In a recent review, Crespo and Fontoura (2007) concluded that no single conclusion can be made. Recent studies have found the specific impact of foreign investments depends on a number of factors such as 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 which are associated with cultures, language, levels of technology, modes of technology transfer, etc., and the trade policy and intellectual property rights protection in the host countries.

3.2 R&D and economic development

The role of technology in general and R&D in particular, economic development has widely been recognised as well. In-house R&D in a country is associated with the level of general economic development. It has been observed that developed countries spend more resources in R&D than developing countries. Meanwhile, a country's spending on R&D generally grows with its economic development (Gao and Jefferson, 2007). One reason for this is simply because countries are more reliant on imported technologies in the early stages of their development, and they do not have the resources and capabilities to develop their own technologies. The experiences of many economies from the USA, to more recent examples such as Japan, Korea and Taiwan have proved that importation–imitation–absorption–assimilation–original innovation is a valid upgrading strategy for lagging countries (Nelson, 1993). For countries in the early period, absorbing imported technologies is particularly critical (Bell and Pavitt, 1997; Cohen and Levinthal, 1989).

Not surprisingly, efforts to analyse innovation in a transitional economy like China have largely ignored indigenous innovative activities, focusing instead on technology transfer from foreign countries (Ho, 1997; Young and Lan, 1997). However, it must be admitted that developing countries do create their own technologies, and many developing countries have strived to become more technologically independent from developed countries (Fan, 2006a,b; Fan and Watanabe, 2006; Gao et al., 2006, 2007; Lu, 2000; Lu and Lazonick, 2001; Simon, 1989; Simon and Goldman, 1989; Sun, 2002a). Developing countries such as India and China are also becoming increasingly important sources of information technologies, and they have attracted many multinational companies to set up R&D facilities (Behrman and Fisher, 1980; Dalton and

Serapio, 1999; Reddy, 1997; Reddy and Sigurdson, 1997; Sun, 2003; Sun et al., 2006; Sun and Wen, 2007a,b; Walsh, 2007). In addition to developing new technologies for their domestic markets, indigenous R&D efforts in developing countries are playing critical roles in monitoring, screening, selecting, implementing and improving transferred technologies, and such 'absorptive' and 'monitoring' efforts are complementary to importation of foreign technologies (Bell and Pavitt, 1997; Cohen and Levinthal, 1989). Unfortunately, the weak absorptive capabilities have been widely reported in China. Many Chinese domestic enterprises are more interested in importing foreign technologies directly rather than learning to develop their technologies, since imported technologies could lead to quicker market success. However, some studies have reported that promising progress has been made in this aspect. For example, in-house R&D has been found to be a significant factor in explaining the innovative performances of Chinese enterprises (Guo and Veugelers, 2006; Hu and Jefferson, 2004; Hu et al., 2005; Liu and Buck, 2007; Sun, 2002b). Among these studies, innovative performance is measured in different ways: total factor productivity (TFP) (Guo and Veugelers, 2006; Hu and Jefferson, 2004; Hu et al., 2005), new product sales (Liu and Buck, 2007; Sun, 2002b) and patents (Sun, 2002b). However, in a recent study, Abraham et al. (2006) found negative impacts of in-house R&D on TFP, based on a panel of data on 10,000 plants in China. One big difference between the study done by Abraham et al. and others is the time of the data: the study by Abraham et al. used a dataset spanning from 2002 to 2004, while the other studies have used earlier data from before 1999. I suspect this could be the source of the different findings; as pointed out in Section 2, in recent years, the Chinese government has pushed very hard to increase S&T resources. I argue that without further improvement in the structure of its NIS, China will not be able to achieve success in making S&T an important engineer for its economic growth. Simply, increasing resources is not enough and must be accompanied by structural reforms in its NIS. Otherwise, much of the increased resources would be wasted.

In conclusion, there is no agreement regarding the impact of FDI and in-house R&D on China's economic development. I want to examine the issues using the most recently published census data and hope it will shed some new light on such matters.

4 Data and model

4.1 Model specification

I used TFP to measure innovative performance or technical efficiency, following the examples of many previous studies. Specifically, I wanted to examine what could explain the sectoral differences of TFP in China. To estimate the TFP for each sector, I adopted the Cobb-Douglas production function as follows:

$$Y_i = \text{TFP} K_i^{\alpha} L_i^{\beta} \quad (1)$$

where Y denotes the gross output value of firms in a sector,[3] K and L are physical capital and labour inputs in each sector, respectively. α and β represent the elasticity of the factors of production in the model. Equation (1) can be rewritten in natural logarithms and TFP can be calculated as follows:

$$\text{LnTFP} = \text{Ln}Y - \alpha \text{Ln}K - \beta \text{Ln}L \quad (2)$$

In this study, I used the total asset (including both fixed asset and operation capital) to represent the capital stock in a sector and total employment for labour, since data for labour-hour were not reported. To test whether or not firms in different sectors follow the same production function, I-applied Chow's test to see if significant differences existed among the regression coefficients for the different groups, where the two-step classification method was used to identify the natural groups among the data.

Then TFP was modelled as being associated with various factors (all the variables will enter the analyses in natural logarithm format)

$$\begin{aligned}\text{LNTFP}_i = &\alpha_0 + \alpha_1\text{LNR\&D} + \alpha_2\text{LNFor\_Inv} + \alpha_3\text{LNFor\_Licensing} \\ &+ \alpha_4\text{LNDom\_Licensing} + \alpha_5\text{LNAssimilation} \\ &+ \alpha_6\text{LNRenovation} + \alpha_7\text{LNExport} + \alpha_8\text{LNSOE} + \varepsilon_i\end{aligned} \tag{3}$$

Operationally, I did the estimation by embedding Equation (3) to Equation (1), combining the two steps since industrial characteristics in R&D, licensing foreign domestic technologies, exports, the presence of SOEs or foreign invested firms may affect firms' choice of the inputs of capital and labour.[4]

The definitions and measurements of the variables are specified in Table 3. In-house technical efforts are represented by two variables: R&D and Assimilation, where R&D represents the in-house R&D spending and Assimilation represents the spending specifically earmarked for 'assimilating' transferred technologies from overseas vendors, while efforts on assimilating domestically transferred technologies are not included in the census. One could argue that in current stage of China, the spending for absorption is going to play stronger roles than other in-house R&D, since such efforts specifically target transferred technologies and should help domestic enterprises to improve their efficiency.

The presence of foreign investments (For_Inv) is represented by different measurements. In addition to total foreign investments (FHKMT), I also examined the specific impacts of investments from Hong Kong, Marco and Taiwan (HKMT) and those from other countries (FIEs). As revealed by many previous studies, the sources of foreign investment could lead to different spillover impacts. For example, Abraham et al. (2006) revealed that HKMT investment showed positive impact on China's domestic firms while FIEs showed negative impacts. Such different results could be due to the smaller technological gap between Chinese firms and HKMT invested firms.

Meanwhile, I - included a number of control variables: spending on licensing foreign investment (For_Licensing), spending on licensing domestic technologies (Dom-Licensing), export, strength of SOEs and spending in technological renovation (refer to Table 3 for the detailed definition and measurement of the variables). Finally, I also entered a few interaction items to the regressions separately to see whether in-house R&D/assimilation effort helped absorption of externally procured technologies.

Table 3 Definition of the variables

Name	*Measurements*	*Expected sign*
Dependent variables: output	Gross output value (100 m yuan)	
Independent variables		
Employment	Total employment (10,000 people)	+
TotAsset	Total Asset (100m yuan)	+
R&D	Industrial R&D spending (100 m yuan)	+
For_Licensing	Spending on licensing foreign technologies per employee (yuan/employee)	+
Assimilation[a]	Spending earmarked for assimilating/absorbing technologies acquired from foreign countries per employee (yuan/employee)	+
Renovation[b]	Spending for technology upgrading and renovation per employee (yuan/person)	+
Dom_Licensing	Spending on licensing domestic technologies per employee (yuan/employee)	+
Export	Percent of export out of gross sales in a sector (%)	+
SOE	Percent of SOEs out of the total asset in a sector (%)	-
FHKMT	Percent of total assets from foreign, including those from Hong Kong, Marco and Taiwan (%)	+
HKMT	Percent of total assets from Hong Kong, Marco and Taiwan (%)	+
FIE	Percent of total assets from foreign economies, excluding those from Hong Kong, Marco and Taiwan (%)	+

[a] All variables are in natural logarithm format in the statistical modelling exercises.

[b] Assimilation refers to efforts to understand, adapt and improve foreign licensed technologies. However, efforts for implementing and improving domestically transferred technologies are not included.

Note: According to the documentation of China's first economic census, technological renovation refers to activities that

> "apply scientific and technological achievements to various areas (including products, equipments and processes et al), 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."

Clearly such efforts are different from R&D, where the major goal is to develop new product and processing technologies.

The presence of foreign invested firms in China's economy could also be represented by employment or market share. Unfortunately, such data are not available to the public.

4.2 Data

The data used in this study came from the *China Economic Census Yearbook* (China State Statistical Bureau, 2006). The census covered all sectors in the secondary and tertiary industries in China and included a wide range of data for Chinese industries in 2004. The published data consisted of three major parts. The first part included basic information such as name, address, sector, date of establishment, ownership, employment, sales, capital, etc. The second part focused on financial data, including detailed information on asset, investment, production, sales, income, costs, tax, profit, etc. The third part concentrated on industrial data, including information about production and sales, inventory, equipment, energy consumption, raw material consumption and S&T. The official published data consisted 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 were tabulated by sector and province. Most data were reported at two-digit sector level while certain data are reported at the three-digit and even four-digit sector levels. I focused on the 165 sectors at the three-digit level in manufacturing. Some variables were missing from certain sectors, and the final analyses focused on the 144 sectors in manufacturing. The published data also focused on those firms whose annual sales were above 5 million yuan, while only a few selected indicators for smaller firms were reported. As such, I focused on those 'bigger' firms.

5 Results

In cross-sectional modelling exercises, one potential problem is whether or not all the sectors follow the same production function. In this study, I conducted Chow's test to see whether or not this is the case. The basic idea of Chow's test is to see if significant differences exist between regression coefficients for two subsets of the data. To reduce the potential subjectivity in classifying the sectors, I adopted the two-step cluster analysis, which can automatically identified the optimal number of clusters as well as the natural groups among the data based on a number of variables. The two-step cluster analysis classified the 144 sectors to two groups and the results are reported in Table 4. The first cluster includes 66 sectors while the second cluster includes 78 sectors. Clearly, the first cluster is more technologically intensive than the second cluster, while the latter is more export-oriented and witnesses more foreign investment. The results of the Chow's test, which are not reported here due to limited space, showed that there is no significant difference between the two clusters regarding the regression coefficients of their production functions. As such, I included all 144 sectors in estimating the production function.

Table 5 reports the descriptive statistics and the correlation coefficients among the variables. A few surprising results showed up, while most of the correlations followed expectations. In particular, *exports* and *foreign investment* show *negative* relationships with output. Such results are surprising, given the importance attached to these two factors to China's economy during the last three decades. This raises the question about the effectiveness and efficiency of China's policies in promoting exports and attracting foreign investments after adopting such a strategy for three decades.

Table 6 shows the detailed comparison among the enterprises of different ownerships. The data show that enterprises in China (both domestic and foreign invested), in general, did not devote much resources to R&D and the average R&D spending was about 0.50% of their output. However, renovation still claimed the largest amount of resources among all the different technological efforts. On average, firms in China spent about 3,180 yuan per employee on renovation, in contrast to 1,187 yuan per employee on in-house R&D, 427 yuan per employee on licensing technologies from foreign countries, 89 yuan on licensing domestic technologies and 66 yuan on absorbing externally acquired technologies.

Table 4 Results of the two-step cluster analysis

Variables	*Cluster 1 (66)*	*Cluster 2 (78)*	*Overall (144)*
Employment	3.70	2.78	3.20
TotAsset	7.26	5.71	6.42
R&D	11.27	9.02	10.05
For_Licensing	6.14	3.74	4.84
Assimilation	4.50	2.66	3.51
Renovation	8.41	6.94	7.62
Dom_Licensing	4.83	3.17	3.93
Export	2.35	3.07	2.74
SOE	2.76	1.82	2.25
FHKMT	3.06	3.58	3.34

Table 5 Descriptive statistics and correlation coefficients for the variables, 2004

	Variables	*A* *Mean*	*B* *SD*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*K*	*L*	*M*	*N*	*O*
C	Output	500.20	1,650.00	1.00												
D	Employment	10.67	44.75	0.92*	1.00											
E	Capital	302.20	1,413.00	0.92*	0.90*	1.00										
F	R&D	0.56	0.63	0.78*	0.70*	0.82*	1.00									
G	For_Licensing	503.00	1,147.00	0.43*	0.25*	0.52*	0.65*	1.00								
H	Assimilation	84.00	149.00	0.34*	0.13*	0.43*	0.59*	0.72*	1.00							
I	Renovation	3,749.00	6,094.00	0.45*	0.27*	0.54*	0.62*	0.64*	0.70*	1.00						
J	Dom_Licensing	143.00	334.00	0.34*	0.13*	0.44*	0.55*	0.62*	0.69*	0.73*	1.00					
K	Export	25.37	21.27	–0.16*	0.01	–0.25*	–0.09	–0.21*	–0.29*	–0.42*	–0.46	1.00				
L	SOE	14.03	13.87	0.28*	0.39*	0.39*	0.35*	0.42*	0.46*	0.60*	0.55*	–0.45*	1.00			
M	FHKMT	34.44	18.96	–0.1	0.10	–0.10	–0.05	–0.22*	–0.26*	–0.47*	–0.42*	0.56*	–0.62*	1.00		
N	FIE	20.20	11.71	–0.07	–0.00	–0.16	–0.20	–0.30*	–0.38*	–0.52*	–0.46*	0.58*	–0.64*	0.86*	1.00	
O	HKMT	14.24	11.24	0.06	0.08	–0.12	–0.04	–0.15	–0.12	–0.34*	–0.32*	0.45*	–0.51*	0.92*	0.63*	1.00

Note: Mean and SD (Standard Deviation) were calculated based on the original variable measurements, while correlation coefficients were calculated based on the natural logarithm transformations of the original variables.

*Represents correlation coefficient significant at the level of 0.05.

Table 6 Innovation in enterprises of different ownerships, 2004

Variables		*Total*	*Domestic enterprises*	*SOES*	*HKMT*	*FIEs*
Outputs (billion yuan)	A	22,232	15,518	2,352	2,439	4,275
%	B	100	69.80	10.58	10.97	19.23
Employments (m employments)	C	93	73.1	8.9	10.4	9.5
%	D	100	78.60	9.59	11.16	10.25
R&D spending(m yuan)	E	110,455	80,505	54,133	8,899	21,052
% (E/A)	F	0.50	0.52	2.30	0.36	0.49
R&D spending/employment (E/C)	G	1,187	1,101	6,066	857	2,208
Renovation (m yuan)	H	295,560	259,062	196,792	14,506	21,992
Renovation/employment (H/C)	I	3,180	3,543	22,052	1,397	2,307
For_Licensing (m yuan)	J	39,736	210,734	24,135	2,203	16,459
For_Licensing/employment (J/C)	K	427	288	2,705	212	1,727
Assimilation (m yuan)	L	6,121	4,205	3,161	311	1,604
Assimilation/employment (L/C)	M	66	57.5	354.2	30.0	168.3
Dom_Licensing	N	8,248	7,324	5,090	409	516
Dom_Licensing/employment (N/C)	L	89	100.2	570.4	39.4	54.1

Note: Financial data in current price (2004).

Source: Data come from China State Statistics Bureau (2006) *China Economic Census Yearbook* (2004).

Compared to the spending patterns in the early 1990s, Chinese enterprises showed some significant changes, particularly for large- and medium-sized enterprises (LMEs) (Table 7). Table 7 clearly shows enterprises in China have stepped up their various technological efforts overtime. Meanwhile, technological renovation remained to be the area that Chinese enterprises spent most of their technological resources. However, enterprises in China seemed to have increasingly realised the importance of in-house R&D and were willing to spend more on such efforts. In comparison, the relative importance of spending on licensing foreign technologies decreased. In-house R&D had taken over the second position from foreign technology licensing since 1999. Similarly, efforts on assimilating foreign imported technologies improved. In 1991, for each dollar spent on licensing foreign technologies, only 4.5 cents were spent on assimilation, which further slipped to 3.6 cents in 1995. From then, the ratio between spending on assimilation and licensing had improved, particularly after 2003 (Figure 5). By 2005, the ratio between assimilation spending and foreign technology licensing had rocketed up to 23.4%. Such a pattern is consistent with the increasing internal R&D spending.

Table 7 Changes of technological efforts in China's LMEs, 1991–2005

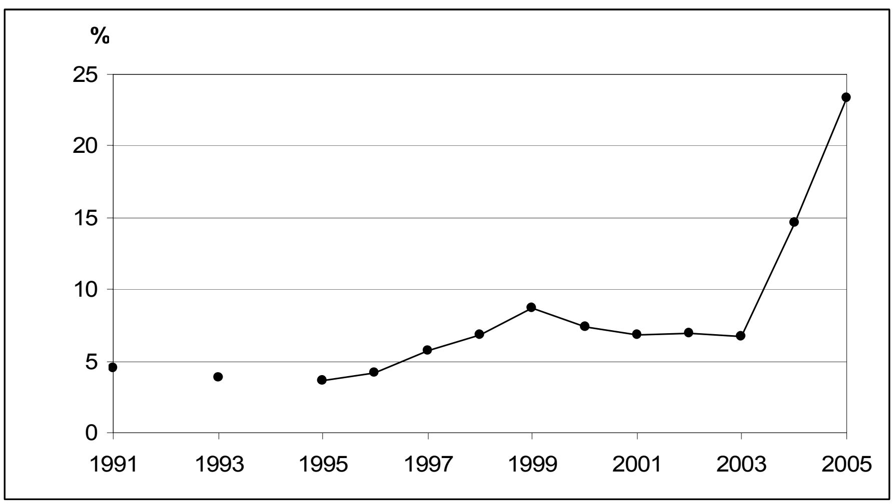
		1991	*2005 (1991 price)*
# of enterprises (unit)	A	14,935	28,567
Employees (1,000 people)	B	31,950	37,420
Sales (b yuan)	C	1,194	8,362
R&D spending (m yuan)	D	5,860	63,378
D/C (%)	E	0.49	0.76
D/B(yuan/employee)	F	183	400
Renovation (m yuan)	G	32,280	141,572
G/B (yuan/employee)	H	1,010	4,430
For_Licensing (m Yuan)	I	9,020	15,044
I/B (yuan/employee)	J	282	470
Assimilation (m yuan)	K	410	3,518
K/B(yuan/employee)	L	13	90
Dom_Licensing (m yuan)	M	370	4,228
M/B (yuan/employee)	N	12	110

Note: Data in table focus on large and medium industrial enterprises in China.

The original financial data were in current price. The data for 2005 were adjusted baseon the industrial output price index published by the Chinese State Statistics Bureau in 2006, *China Statistical Yearbook*.

Source: MOST (2006).

Figure 5 Spending on technology assimilation and foreign technology licensing among China's large and medium enterprises, 1991–2005



Tables 8–10 report the results from the regression analyses. The basic model (I) did not include the interaction terms while other models did. Table 8 shows the results where the presence of foreign investment is measured by the capital share of all foreign investments including both FIEs and HKMT invested enterprises, while Tables 9 and 10 separate FIEs from HKMT invested enterprises to examine their spillovers impacts, since Abraham et al. (2006) found that western investment shows negative while HKMT investment shows positive spillover effects on Chinese enterprises.

Table 8 Regression analyses I: all foreign investment included

Dependent variable: output	*(1)*		*(2)*		*(3)*		*(4)*	
Independent variables	*B*	*SE*	*B*	*SE*	*B*	*SE*	*B*	*SE*
Constant	0.527	0.3780	2.126	1.0400	0.851	0.5543	0.709	0.1040
Employment	0.043	0.0934	0.058	0.0884	0.060	0.1008	0.057	0.0317
TotAsset	1.033***	0.0965	1.025***	0.0939	1.004***	0.1121	1.009***	0.0248
R&D	–0.035	0.0313	–0.195**	0.0875	–0.051	0.0353	–0.029	0.0231
For_Licensing	–0.014	0.0188	–0.013	0.0179	–0.062	0.0535	–0.033	0.0435
Assimilation	0.021	0.0214	0.012	0.0219	0.020	0.0212	–0.004	0.0260
Renovation	–0.036	0.0434	–0.019	0.0401	–0.037	0.0431	–0.040	0.0441
Dom_Licensing	0.021	0.0259	0.028	0.0263	0.020	0.0259	0.018	0.0383
Export	0.049	0.0439	0.048	0.0432	0.040	0.0445	0.043	0.0574
SOE	–0.130***	0.0385	–0.144***	0.0391	–0.135***	0.0400	–0.130***	0.0057
FHKMT	–0.039	0.0573	–0.510*	0.2774	–0.042	0.0575	–0.043	0.1040
R&D*FHKMT			0.045*	0.0250				
R&D*For_Licensing					0.005	0.0056		
Assimilation* For_Licensing							0.007	0.0317
# of observations	144		144		144		144	
Likelihood ratio Chi-square	403.20		406.51		404.15		404.570	
Significance	0.000		0.000		0.000		0.000	

*Significant at the level of 0.1.

**Significant at the level of 0.05.

***Significant at the level of 0.01.

Table 9 Regression analyses II: foreign investments excluding those from Hong Kong, Macao and Taiwan

Dependent variable: output	*(1)*		*(2)*	
Independent variables	*B*	*SE*	*B*	*SE*
Constant	0.507	0.3464	1.371	0.8029
Employment	0.031	0.0916	0.041	0.0879
TotAsset	1.039***	0.0957	1.028***	0.0945
R&D	–0.030	0.0323	–0.114*	0.0623
For_Licensing	–0.014	0.0189	–0.014	0.0183
Assimilation	0.023	0.0219	0.018	0.0217
Renovation	–0.039	0.0436	–0.027	0.0405
Dom_Licensing	0.019	0.0259	0.022	0.0261
Export	0.048	0.0415	0.042	0.0408
SOE	–0.131***	0.0369	–0.142***	0.0388
FIE	–0.045	0.0490	–0.348	0.2450
R&D* FIE			0.029	0.0219
# of observations	144		144	
Likelihood ratio Chi-Square	403.82		405.76	
Significance	0.000		0.000	

*Significant at the level of 0.1.

**Significant at the level of 0.05.

***Significant at the level of 0.01.

Table 10 Regression analyses II: investments from Hong Kong, Macao and Taiwan only

Dependent variable: output	*(1)*		*(2)*	
Independent variables	*B*	*SE*	*B*	*SE*
Constant	0.301	0.3250	0.757	0.5437
Employment	0.044	0.0981	0.051	0.0761
TotAsset	1.028***	0.0998	1.030***	0.0785
R&D	–0.032	0.0313	–0.085	0.0599
For_Licensing	–0.015	0.0192	–0.015	0.0200
Assimilation	0.017	0.0202	0.012	0.0235
Renovation	–0.028	0.0438	–0.021	0.0407
Dom_Licensing	0.023	0.0262	0.028	0.0263
Export	0.035	0.0437	0.041	0.0308
SOE	–0.106***	0.0331	–0.110***	0.0350
HKMT	0.017	0.0306	–0.181	0.2005
R&D* HKMT			0.019	0.0188
# of observations	144		144	
Likelihood ratio	402.70		403.70	
Chi-square				
Significance	0.000		0.000	

***Significant at the level of 0.01.

**Significant at the level of 0.05.

*Significant at the level of 0.1.

Source: Ministry of Science and Technology (2006).

Among all the regression analyses, two consistent findings can be observed. One is that capital (TotAsset) shows consistent, significant and the strongest *positive* impact on the output, and states enterprises (SOEs) show consistent, significant, but *negative* impact on the output. Such results clearly demonstrate that the Chinese economy still heavily relied on capital accumulation and SOEs were still dragging the efficiency of China's economy even after so many years of reforms.

On the variables representing technological efforts, the analyses show consistently *negative*, though insignificant, impacts of in-house R&D, while assimilation shows *positive* (except in one case), though insignificant, impact on output. Such results confirm the finding of the recent study done by Abraham et al. (2006), while contradicting those from others (Guo and Veugelers, 2006; Hu and Jefferson, 2004; Hu et al., 2005; Liu and Buck, 2007; Sun, 2002b). The results also show that spending on licensing or assimilating foreign technologies, renovation or domestic technology purchasing did not show significant impacts on the sectoral difference of industrial output. Interestingly, spending on licensing foreign technologies and renovation showed *negative*, though insignificant impact on the output.

On the spillover impact of foreign investment, it is surprising to note that the different measurements of foreign investment (FHKMT, HKMT or FIE) showed consistently *negative*, though insignificant, impact on the output. Such results are contrary to the findings of the studies done by Hu and Jefferson (2002), Huang (2005) and Lo (2006). It is also interesting to note that export was ineffective in explaining the sectoral difference of output, though such impacts are positive.

However, the interaction term between in-house R&D and FHKMT/FIE/HKMT investments did show positive, though insignificant, impact on the sectoral difference of output. The analyses also revealed positive impacts of the interaction term between R&D and licensing foreign technologies as well as the interaction term between assimilation and licensing foreign technologies. Such results showed the importance of in-house technological efforts (including both original R&D and those efforts earmarked for assimilating foreign technologies) in helping domestic firms to capture the spillovers effects of foreign investment and to effectively utilise the technologies imported from foreign countries. However, I need to point out that only in one occasion did the interaction term show *significant* impact on the output in all six sets of analyses. As such, one should be cautious in interpreting the results.

6 Conclusions and discussion

This study reveals that since the mid-1990s, significant changes have occurred in China's industrial innovation. Chinese enterprises have increased their in-house technical effort (both R&D and assimilation efforts), while the importance of licensing foreign technologies has declined. Such a pattern suggests that Chinese enterprises have realised the importance of in-house R&D in their development. The study also reveals that Chinese domestic enterprises spent most of their revenues on in-house R&D than foreign invested enterprises, though R&D spending per employee in foreign firms was much higher than that for Chinese domestic enterprises. Interestingly, this study also found that Chinese SOEs were spending much more resources on R&D than their foreign enterprises. Such findings confirmed the general observation that foreign firms are less likely to engage in R&D than domestic firms due to their access to more advanced technologies from parent companies (Jefferson et al., 2003; Sun, 2002b).

The study demonstrated that China's economy still heavily depended on capital accumulation, instead of innovation. It is also not surprising to note that state-owned enterprises were still a big drag on China's economy after so many years' struggles and reforms. More importantly, this study finds that neither foreign investment nor in-house R&D effectively explained the sectoral differences of economic efficiency in China. Such results are in conflict with those from the majority of earlier studies, while a few recent studies have revealed similar results. Among all these studies, the most significant difference can be observed between this study and the one done by Liu and Wang (2003), who analysed the 1995 industrial survey data and found that both foreign investment and in-house R&D have significant and positive impacts on economic efficiency measured by TFP.

I argue that the findings from this study raise a series of questions on a number of critical issues related to foreign investment and China's recent S&T drive to become an innovation-oriented country, the two important strategies for China's economic growth. To begin with, the role of foreign investments, as recognised, has made significant contribution to China's miracle growth during the last two decades. However, this study shows foreign investments had no impacts on the output. Many foreign enterprises are using China as an exporting platform and have helped to turn China to the 'World's Factory'. Such contributions are undeniable. Nevertheless, it seems that it is the time to reassess this strategy. Fair, foreign firms have provided much needed jobs and capitals for China's economic development. But jobs and capitals are not the only benefits expected by the Chinese government from foreign investments. More importantly are their advanced technologies and management practices. It is the Chinese government's hope that such technologies will be transferred or spilled over to Chinese domestic firms. This study shows that such anticipated positive spillovers do not exist, though they did show positive impacts in the early period as revealed by Liu and Wang (2003) and others. Does this mean that the crowding-out impact of foreign investment has become so strong that the positive impacts through competition, demonstration, labour mobility or industrial value chain linkages have been cancelled out? I do not have definite answers for such questions. Nevertheless, one has to ask whether or not the current strategy reliant on foreign investment has gone too far (Huang, 2005), considering the preferential policies granted to foreign investors and the much more restrictive treatments received by China's private sectors. Indeed, the Chinese government has recently changed the policy on foreign investment. From 2008, the same corporate income tax rate will be applied to domestic and foreign businesses in China and foreign investment will receive similar treatments as domestic enterprises.

Moreover, no relationship between in-house R&D and innovation was found and this casts doubts on the effectiveness of China's innovation strategies. Indeed, neither in-house R&D, nor the spending on licensing foreign technologies and renovation showed impact on output. As I demonstrated earlier in the study, China has experienced so-called 'S&T take off' since the mid-1990s and a large amount of resources have been poured into technological efforts. The results from this study demonstrate that such tremendous increases on technological spending have not paid off in China's economic development, though they may have led to increasing numbers of papers, patents, etc. The unexpected relationship between in-house R&D, foreign technology licensing and renovation on the one hand and output on the other hand be due to two reasons. One possible reason (I hope) is that a temporal lag exists between the moment of S&T take off and when S&T makes significant contributions to economic progress. The increased S&T resources and efforts may lead to new technologies first before such new technologies are translated to economic significance. It takes time from putting in resources to the moment when significant economic impact is observed. However, a similar study done by Liu and Wang (2003) did reveal positive impacts of in-house R&D on TFP based on the 1995 survey data. If time lag is a significant issue, it should have the similar impact in the early period as well, unless significant changes have occurred between 1995 and 2004. Unfortunately, our data did not allow us to test the hypothesis. It would be a valuable exercise for future studies to use panel data to test the impact of time lags.

Another possible explanation for the lack of relationship between in-house R&D and output may also suggest that much of the recent increased industrial S&T resources have not been efficiently allocated among the different sectors. China's industrial firms in certain sectors have not been able to capitalise on such increased resources and translate them into technological efficiency and market competitiveness. If this is the case, it signals the critical importance to further reform Chinese enterprises, for them to learn how to efficiently manage their in-house R&D organisation and to better integrate their R&D effort with other activities such as marketing, sales and production. Given the positive impact of in-house R&D found on innovation performance among Chinese enterprises in the earlier period, the second scenario appears to be more plausible. However, the insignificant impact of in-house R&D on output in *no way* suggests that

Chinese firms should give up their in-house R&D efforts. Indeed, the results from this study also show that in-house R&D and assimilation efforts do help domestic firms to capture the spillover effects from foreign investment and to utilise technologies imported from foreign countries. What Chinese enterprises need to do further is to better organise their R&D efforts and to become more efficient and effective in using such resources.

No relationship between export and industrial output is found and this finding is also interesting and surprising, given the importance attached to the export-oriented strategy in China. The huge international trade surplus for China has become an important source of global tensions between China and many other countries, particularly the USA and countries in Western Europe. Yes, exports have helped China to generate lots of jobs and tremendous amounts of trade surpluses and fuelled its economic growth through the last three decades. However, whether or not such a strategy is sustainable has become a source of disputes among academics as well as policy makers. As such, the Chinese policy makers have recently initiated a few policies that in effect have slowed the growth of export. Such policies include reducing the export tax rebate and raising the exchanging rate of the Chinese currency. These policies, along with the surging prices of oil and many other raw materials, as well as the recent changes of the Chinese labour laws requiring businesses to pay pension funds, medical insurance and many others, have led to tremendous pressures on the operations of many domestic firms which focus on the export market. Initiating so many policies in such a short period of time is controversial, and some scholars consider such actions 'suicidal' and will have severe, negative impact on China's economy.[5] Based on the findings of this study, I believe it is necessary for China to make a transition to an economy less reliant on export, but more on the domestic market, particularly the domestic consumer markets. However, such a transition needs to be gradual, and step-by-step. Maybe the biggest lesson from China's success during the last three decades is to be cautious and careful in designing and implementing any reform policies. Time has shown and will continue to show the value of Deng Xiaoping's approach of 'crossing the river by feeling the stones'.

What we can conclude from this study includes:

1 capital accumulation is still the biggest source of China's economic growth

2 state-owned enterprises are still dragging down China and need further reforms

3 neither the spillover effects nor export can significantly explain the sectoral output of China

4 technological efforts have not made significant contributions to China's economy, though China has raised its spending/investment significantly in such areas.

This study reveals many surprising findings. However, one needs to be cautious since such a study was only based on the cross-sectional data at the three-digit sector scale in 2004. Whether or not such findings will hold for more recent data and more detailed data remains to see. To some extent, this study raises more questions than answers them. More studies in the future will add value to such critical questions.

Acknowledgements

I am grateful for financial support from the National Science Foundation. I conducted the research on my sabbatical in 2007 and wish to thank the California State University Northridge for the additional support. I also want to thank the two reviewers for their very detailed and constructive comments and suggestions, which have helped to improve this paper significantly.

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Notes

[1] The term *Zizhu 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 *Zizhu 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 Ministry 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, 'indigenous innovation' which we feel probably reflects the intention of the Chinese government.

[2] The ratio has been changed to 1.34% after China readjusted its GDP after its economic census in 2004.

[3] Ideally, value added should be used in the production here. Unfortunately, the census did not make such data available.

[4] Thanks to the comments and suggestion from an anonymous reviewer for this.

[5] Such opinions were expressed by prominent scholars through my personal communication when I visited China in the summer, 2008.