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RESEARCH AND STATISTICS BRANCH

WORKING PAPER 05/2008

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External Technology Purchase and Indigenous Innovation Capability in Chinese Hi-Tech Industries

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Vienna, 2008

Acknowledgements

The author acknowledges the support provided by UNIDO to participate in the First Annual Conference of the Sanjaya Lall Programme for Technology and Management for Development "Confronting the Challenge of Technology for Development: Experiences from the BRICS", University of Oxford, 29-30 May 2008.

Jaime Moll de Alba was responsible for backstopping the support provided by UNIDO as well as the production of the paper. Francis L. Bartels and Jaime Moll de Alba, UNIDO staff members, provided substantive comments. The author is grateful for the financial support provided by National Natural Science Foundation of China (Project No.: 70602005). Robert Cox was responsible for stylistic revision and Griselda Sanz for graphic design.

Abstract

This paper empirically investigates the effect of three types of investment in acquiring technological knowledge—in-house R&D, importing foreign technology and purchasing domestic technology—on the innovation capability of Chinese state-owned enterprises in hi-tech industries. Based on a dataset constructed from official statistics on a panel of 21 hi-tech sectors during the period 1995-2004, I estimate an augmented knowledge production function with the sector as units of analysis. The results show that investing in foreign technology alone does not facilitate introduction of innovation in state-owned enterprises, unless it is coupled with a firm's own in-house R&D effort. Domestic technology purchases have a favourable direct impact on innovation, suggesting that firms have little difficulty in absorbing domestic technological knowledge. The innovation and learning role of R&D also varies with time and across industries.

1. Introduction

For firms in developing countries, use of technology developed abroad is usually considered to be an expedient way to develop and expand manufacturing capacity (Amsden, 1989). However, the importance of external technology on technological competence and innovation capability depends on whether recipient firms have related prior knowledge or absorptive capacity to understand and exploit technological opportunities (Cohen and Levinthal, 1990). One case that occurs often in developing countries is that very weak technological capability of domestic firms forces them to rely continuously on foreign technology. Such examples can be found in the Chinese automobile and civilian aircraft industries, which are discussed in Lu (2005) and Lu and Feng (2005), respectively. Due to the tacit and context-specific nature of technological knowledge, it is difficult, if not impossible, for recipient firms to acquire innovation capacity through the mere importation or purchase of external technology. For instance, Nelson and Winter (1982) pointed out that organizational routines based on which technology and innovation are developed are difficult to transfer across firms. In the case of China, the presence of foreign capital as well as use of imported technology from developed countries has contributed considerably to the country's rapid economic growth since the 1980s (Hu and Jefferson, 2002; Liu, 2002; Liu and Wang, 2003; Madariaga and Poncet, 2007; Yao, 2006; Zhang, 2001). Despite the Chinese Government's initial policy goal of trading market for technology, it is often difficult for Chinese firms to obtain state-of-art technology through foreign direct investment inflow and import of foreign technology (Wang and Gao, 2006). As a result, domestic firms are constantly dependent on foreign firms for core technologies in many industries (Lu and Feng, 2005).

Due to their rather weak technological capability, indigenous firms in most developing countries such as China often look for appropriate technologies from domestic sources including university labs, government-run research institutes or, even, local competitors. Regardless from which sources this external knowledge is acquired, one recurring question is whether and under what conditions recipient firms can assimilate and effectively exploit such knowledge to build up their own innovation capability. According to Cohen and Levinthal (1989), conducting in-house R&D is not only crucial for firms to innovate and generate new knowledge but also important for them to learn and create absorptive capacity. Given the dual functions of in-house R&D, what is the pattern of innovation and learning among non-frontier firms in developing countries? How and under what conditions can these firms take advantage of the three different sources of knowledge—in-house R&D, imported foreign technology, acquired domestic technology—to promote innovation? Does the pattern of learning and innovation in firms vary with time and across industries?

To address these issues and examine a model for innovation and learning among firms in developing countries, this paper particularly focuses on two forms of external disembodied technological knowledge: technology imported from foreign countries and domestic technology licensed by universities, research institutes or other domestic firms. Following the definition of the Chinese National Bureau of Statistics (CNBS), foreign technology import (FTI) expenditures are defined as including purchases of design knowledge, formulae, drawings, processes, patents and know-how and key equipment closely related to new product development. They do not include those used directly for production, such as production lines, complete knock-down kits and turn-key facilities (Liu and White, 1997). In this sense, a large portion of FTI expenditures is spent on disembodied knowledge. FTI mainly takes the form of technological licensing and is substantially different from the import of foreign machinery and equipment, which represents a form of embodied knowledge. Similarly, domestic technology purchase (DTP) refers to the licensing of outside technologies developed by universities, research institutes or other firms, representing a form of knowledge transfer from domestic sources. Hence, both FTI and DTP reflect firms' efforts to acquire technological capabilities from external sources. They can be transacted in markets for technology, as defined in Arora *et al.* (2001). The major difference between FTI and DTP lies in the source of technological knowledge.

This analysis is based on a panel dataset constructed from publicly available official statistics on five Chinese hi-tech industries: medical and pharmaceutical products, air- and spacecraft, electronic and telecommunication equipment, computer and office equipment, and medical instruments and meters. The definition of Chinese hi-tech industries is similar to and comparable with that used in OECD countries, although they are not as R&D-intensive as their counterparts (Xu, 2000). With four-digit Chinese standard industrial classification (SIC) sector as unit of analysis, I constructed a panel of 21 sectors and analyzed sector-level data for the period from 1995 to 2004. Table A1, in the appendix, gives a list of all sectors included. Drawing upon the previous studies (Archibugi, 1992; Acs *et al.*, 2002; Furman *et al.*, 2002), I used domestic patent application counts to measure innovation capability. A firm's innovation capability is thought to be determined by three sources of technological knowledge that the firm acquires from in-house R&D, foreign technology import and domestic technology transfer. The contribution to innovation capability of three sources of knowledge is empirically estimated within a framework of knowledge production function (Hall and Mairesse, 1995; Basant and Fikkert, 1996; Hu *et al.*, 2005).

This paper contributes to the literature on absorptive capacity and dual role of in-house R&D. Estimated results show that domestic firms in hi-tech industries can gain leverage by investing in both in-house R&D and FTI, while technology imports alone do not contribute to the rate of patenting. By contrast, investing in domestic technology alone facilitates a firm's innovation. The firm can easily assimilate and utilize domestic technological knowledge, independent of absorptive capacity. This suggests that absorptive capacity is crucial for assimilating foreign technology. It is also found that the learning and innovation effect of R&D is different across sectors having evolved with time.

The remainder of this paper is organized into four sections. The first presents a brief review of relevant literature. The second introduces the estimating strategy that I employed in the analysis and describes data construction and summary statistics.

Results and main findings are reported in the third. The last concludes with some caveats and areas for further research.

2. Literature Review

The effect of in-house R&D on firms' innovation has long been recognized since Schumpeter (1942), while the relationship between R&D and innovation outcome has been extensively studied within the framework of knowledge production function in previous empirical studies (see, for example, Hausman *et al.*, 1984; Jaffe, 1986; Cincera, 1997; Furman *et al.*, 2002). Beside in-house R&D, a firm can also obtain useful technological knowledge from technology markets (Arora *et al.*, 2001), which in turn contribute to the firms' knowledge generation. For firms in later-comer economies, exploiting technological knowledge developed externally often ranks among important catching-up strategies (Amsden, 1989; Arora *et al*., 2001). The importance of knowledge spillovers embodied in foreign technological products has been highlighted in the literature of international R&D spillover (Grossman and Helpman, 1991; Coe and Helpman, 1995). MacGarvie (2006) claims that import-related embodied knowledge spillovers can occurs through three mechanisms: demonstration effects, linkages with foreign buyers and suppliers and labour mobility. Regarding the licence-related disembodied knowledge, it is acquired by recipient firms through a direct and formal channel and, thus, may be better exploited directly, although the aforementioned mechanism may work as well. However, because tacit knowledge associated with use of external technology does not easily transfer with the purchase of a technology, whether the licensees can effectively take advantage of such disembodied knowledge is contingent on the level of their prior related knowledge or absorptive capacity. According to Cohen and Levinthal (1990, p128), absorptive capacity refers to "the ability of a firm to recognize the value of new, external information, assimilate it and apply it to commercial ends". It is largely related to the level of the firm's prior related knowledge, which can, in turn, be developed through its own R&D efforts.

Recent studies have confirmed the contribution of FTI to productivity and growth in developing countries (Basant and Fikkert, 1996; Liu & White, 1997). However, the impact of foreign technology on the innovation capacity of local firms has been largely unexplored. Even worse, the limited findings in previous works are mixed or inconclusive. For instance, Liu and White (1997) found that firms can gain leverage when investing in both R&D personnel and foreign technology in highly innovative industries, while imported technology alone has no direct impact on a firm's innovation measured by the share of new product sales. By contrast, Liu and Buck (2007) found that learning-by-importing-technology can accelerate a local firm's introduction of new products directly, independent of absorptive capacity. Two empirical studies provide contrasting results on the importance of absorptive capacity.

Cohen and Levinthal (1990) posited that the importance of absorptive capacity is determined by both the quantity of knowledge to be assimilated and utilized and the difficulty of learning. The difficulty or ease of learning is largely determined by the characteristics of the underlying technological knowledge, which include complexity of knowledge to be assimilated and degree to which outside knowledge is targeted to the needs and concerns of a firm. Following this logic, one may expect that a systematic difference exists between technological knowledge imported from foreign countries and that licensed from domestic sources. First, since technological level in many Chinese industries is far from technology frontiers, foreign imported technology is normally more complex and sophisticated than the best domestic technology. Secondly, foreign technology is less likely to suit the needs or concerns of Chinese indigenous firms than domestic technology. Moreover, since labour mobility is much easier within a country than across national boarders, related technological knowledge may not be essential for a recipient firm to exploit external knowledge generated by another local firm, since it can easily acquire such capacity by hiring those with the requisite knowledge from other local firms. In this sense, it might be more difficult for a firm to assimilate and exploit foreign technology than domestic technology.

Based on the argument of technology gap, complexity and sophistication of external knowledge can be said to have influential impact on a firm's incentive to develop absorptive capacity. For instance, researchers found that only firms above a certain technological level were likely to benefit from external technology spillovers (Borensztein *et al.*, 1998; Glass and Saggi, 2002), implying that the larger the technology gap, the more crucial the absorptive capacity. In China, the technology gap between a firm's own technology and imported foreign technology is much larger than that between its own technology and licensed domestic technology. Thus, I expect that the moderating effect of absorptive capacity on the effect of external knowledge will be different between the two sources of outside knowledge.

Despite its important moderating effect, how is absorptive capacity developed? As Cohen and Levinthal (1989) argued, in-house R&D not only generates new knowledge (i.e., innovation effect) but also contributes to a firm's absorptive capacity (i.e., learning effect), implying that a firm's R&D has dual functions. Hence, a firm can accumulate prior knowledge and create absorptive capacity through R&D activities. The current literature has noted that the learning effect of R&D in developing absorptive capacity is contingent on the level of technology gap. For example, Griffith *et al.* (2004) and Kneller (2005) showed that the further a country is behind the world technological frontier, the greater the importance of its R&D investment in creating absorptive capacity. Castellani and Zanfei (2003) reported a similar result, in which the contribution of international technology spillover is dependent on the technology gap between foreign and recipient domestic firms. Girma (2005) noted that a threshold of absorptive capacity existed for effective technology spillover to occur. These studies suggest that a firm with a lower level of absorptive capacity faces a more difficult learning environment. In this case, the marginal effect of R&D on absorptive capacity will be increased (Cohen and Levinthal, 1989). One can postulate that a non-frontier firm's R&D investment will be more important to building absorptive capacity than to generating new knowledge.

The discussion of the dual functions of R&D has important implications for the evolution of firms' learning and innovation behavior. During the last 30 years, the rapid development of the Chinese economy has brought about a noticeable improvement in Chinese firms' absorptive capacity and innovation capabilities (Li, 2007). Following the aforementioned logic, as a firm's absorptive capacity improves, the learning effect of its R&D should become less important and the innovation effect more prominent. Whether this holds true for China is a hypothesis that this study tests empirically.

Given the fact that the importance of a firm's absorptive capacity is related to the characteristics of outside knowledge to be assimilated and exploited, development of absorptive capacity is industry-specific and path-dependent. This is simply because systematic differences exist between industries regarding their knowledge base and technology paradigms (Malerba, 2005). Nelson and Winter (1982) predicted that the more tacit the relevant knowledge the more difficult it is to assimilate and exploit and, hence, the stronger the incentive a firm has to build up absorptive capacity. Since greater technological opportunity represents greater amount of external knowledge, which, in turn, increases the importance of the firm's absorptive capacity, Cohen and Levinthal (1990) postulated that the faster the pace of knowledge generation in a field the more necessary are the R&D efforts to developing absorptive capacity. Considering that sectors are in different technology regimes and at different stages of the industrial cycle, I hypothesize that the learning and innovation effects of in-house R&D are disparate across sectors.

3. Empirical Strategy

3.1. Methodology

In order to compare the impact of knowledge developed from different sources on innovation and empirically examine the mode of learning and innovation in Chinese indigenous firms, I propose an augmented knowledge production function as the base of economic analysis and use the number of domestic patent applications as the measure of innovation. Taking into account the specific nature of patent counts in the dataset (Cameron and Trivedi, 1998), I assume that the number of sector level patents can be specified in a count panel data model as the following:

$$E(Patent_{it}) = \exp\left\{ \begin{array}{l} \delta_t + \beta_1 RD_{it} + \beta_2 FTI_{it} + \beta_3 DTP_{it} + \beta_4 (RD_{it} * FTI_{it}) \\ \quad + \beta_5 (RD_{it} * DTP_{it}) + \beta_6 JVPCT_{it} + \beta_7 INTEN_{it} + \beta_8 CAPIT \end{array} \right\}, \qquad (1)$$

$Patent_{it}$ are the patent counts for the *i* sector in year *t*. RD_{it}, FTI_{it} and DTP_{it} represent log-scaled knowledge stocks KR_{it}, KF_{it} and KD_{it}, respectively. KR_{it} is the stock of technical knowledge generated by domestic firms' in-house R&D investment in sector *i* at year *t*; KF_{it} is the stock of foreign technical knowledge imported by sector *i*; and KD_{it} is the stock of domestic technology acquired by firms in sector *i*. δ_t represent dummy years ; and βs are coefficients to be estimated from the model.

Taking into consideration that absorptive capacity can be created through in-house R&D, I include interaction term (*RD**FTI*) and (*RD**DTP*) to account for the moderating effect of absorptive capacity on assimilating and utilizing knowledge generated through FTI and DTP, respectively. Thus, the model specification (1) incorporates the dual role of in-house R&D. It implicitly posits that a firm is unable to assimilate externally generated knowledge passively. In order to exploit such knowledge, a firm must invest in absorptive capacity, which can, in turn, be created by investment in R&D.

Along with the three variables of knowledge capital, I consider three control variables in the model. The first variable, *JVPCT,* is the sales share from overseas (including Hong Kong Special Administrative Region of China, Macao Special Administrative Region of China and Taiwan Province of China) owned or invested by firms in each sector. It is intended to capture the implicit knowledge spillover effects from these firms. Since the unit of this analysis is the hi-tech sector, two sector level variables (*INTEN* and *CAPIT*) are incorporated to control for sector heterogeneity. The variable *INTEN* reflects sector-level R&D intensity as defined by R&D expenditure divided by total sales. *CAPIT* is sectoral capital intensity, measured as the ratio of the book value of fixed assets to total outputs. By including dummy years in the model, time-related sector-wide effects are subsumed in the coefficient of dummy years.

FDI is also an important channel through which foreign technologies influence accumulation of domestic technological capabilities (Cheung and Lin, 2004). Unfortunately, I am unable to take this into account due to the lack of sector-level FDI information in the data. Technical information provided by original equipment manufacturer (OEM) contracts, reverse engineering efforts and labour mobility is another potential channel for diffusion technology (Liu and Wang, 2003). Since most of these leave no paper trail from which to analyze flow of technology and its impact, in the proposed model, I focus on three sources of technological knowledge only: in-house R&D, FTI and DTP.

3.2 Data and measurement

Given the importance of high-tech industries to the national economy, CNBS has been collecting information on science and technology from hi-tech firms. For the purpose of this analysis, I used this official information to investigate innovation activities across hi-tech sectors. Specifically, the data used all come from office statistics published by CNBS, in the series *The Chinese Hi-Tech Industry Statistical Yearbook* (2002-2005), which covers the period from 1995 to 2004. This *Yearbook* contains about 30 major indicators of innovation activities in five Chinese hi-tech industries: pharmaceuticals, aircraft and spacecraft, telecom, computers and instruments. Firm-level data were originally reported to CNBS by all large and medium-sized enterprises (LME). To maintain the confidentiality of the firms' information, CNBS aggregated firm-level data according to a combination of firm ownership and four-digit SIC sectors. In this study, I consider only state-owned enterprises, which are sometimes referred to as indigenous firms. This is mainly because data information on FTI and DTP is unavailable for firms under other ownership.

Although both Liu and White (1997) and Liu and Wang (2003) used new product sales as a measure of innovation, this paper employs the domestic patent applications count as a proxy indicator of endogenous innovation output, following the conventions in the literature (Archibugi, 1992; Acs *et al.*, 2002; Furman *et al.*, 2002). In terms of measuring the endogenous or indigenous feature of innovation, these two measures are largely different. In China, if a product is designated by the Government as new, the firm can obtain a tax subsidy from the provincial or national Government. For this reason, firms have a strong incentive to over-record the sales of new products. Even worse, the procedures for new product approval are neither completely standardized nor comparable between regions. The newness of products is a relatively arbitrary and geographically-bounded concept. According to Chinese statistical convention, a product designated as new can be just new to a local market, such as a county, a city or a province, whether or not it has been on the market in other places. Or a product can be regarded as new as long as it is new to a firm and has not been produced for more than one year. Thus, the measure of new product sales will inevitably include some measurement bias.

By contrast, the procedures for filing patents are uniform across all sectors and regions. Moreover, patents usually contain more technological improvements and/or innovative ideas than new products, and have to be at least new to the country. In this sense, patents can be regarded as a better refection of endogenous or indigenous innovation efforts. The Chinese patent system classifies patents into three categories according to their innovativeness and sophistication: invention, utility model and exterior design. Patents analyzed in this study all refer to invention applications representing the most technologically sophisticated and new-to-the-country innovative outputs. Although there are also measurement issues associated with using patents to measure innovation

(Pavitt, 1988; Griliches, 1990; Archambault, 2002), it is the best indicator available in the CNBS aggregated level dataset to reflect the indigenous nature of an innovation.

In the empirical estimation of R&D-patenting knowledge production functions, two measures of R&D, or knowledge, are usually considered. For example, Hausman *et al.* (1984), Acs and Audretsch (1988), Cincera (1997) and Blundell *et al.* (2002) used the current and past flow of R&D expenditure as inputs, and assumed that all past R&D investments are substitutes, with a unit elasticity of substitution. Due to the high persistency of R&D expenditure, this specification often leads to multi-collinearity problems between lagged regressors. Drawing on empirical literature on R&D and productivity (Hall and Mairesse, 1995), Crépon and Duguet (1997), instead, employed estimated R&D capital stock. According to these studies, the annual flow of R&D expenditures is taken as investments adding to a firm's knowledge capital. Knowledge capital depreciates over time, so that the contribution of past R&D becomes less valuable as time passes (Griliches, 1979). One advantage of this specification is that it allows for both complementarity and depreciation in past R&D expenditures. This paper adopts the second approach, to construct stock variables for the three different sources of knowledge.

Following common practice in previous works, the variable of knowledge capital stocks generated from R&D can be estimated with a perpetual inventory model (Hall and Mairesse, 1995). The initial knowledge stock SR_1 and the knowledge stock at the beginning of year t (SR_t) are computed from annual R&D investment (FR_t), as in the following:

$$SR_1 = \frac{FR_1}{(g+\delta)}, \qquad (2)$$

$$SR_t = (1-\delta)SR_{t-1} + FR_{t-1}, \qquad t \geq 2. \qquad (3)$$

Here, g denotes the pre-sample growth rate of annual R&D flow FR_t and δ is the annual depreciation rate of R&D investment. One drawback associated with using knowledge stock in (1) as technological inputs is that it ignores the contribution of current R&D investment in patenting. Hall *et al.* (1986) showed that a strong contemporaneous relationship exists between in-house R&D investment and patenting. In order to incorporate the contemporaneous effect, I use the in-house R&D stocks at the middle of year t, which are computed as:

$$KR_t = (SR_t + SR_{t+1}) / 2, \qquad 1 \le t \le T. \tag{4}$$

Both SR_t and SR_{t+1} are obtained from (2) and (3). The effect of contemporaneous R&D investment is, thus, reflected in KR_t through SR_{t+1}. To compute the initial R&D stock SR_1, two parameters, g and δ, have to be determined (Griliches and Mairesse, 1984). Since the specification of δ and g does not affect the results significantly, as confirmed in the literature (Hall and Mairesse, 1995), I assumed a pre-sample growth rate and an annual depreciation rate, both at 15 per cent as in previous studies (Hu and Jefferson, 2004). The same approach is adopted to construct the knowledge stocks generated from FTI and DTP. In computation, in-house R&D, FTI and DTP expenditures are all adjusted by GDP deflators to their 1995 constant values.

Table 1: Descriptive Statistics

Variable	Mean	Std.	Min	Max
Patent	40.989	74.220	0	621
RD	0.731	1.317	-3.277	3.690
FTI	-0.176	1.827	-5.353	3.876
DTP	-2.114	1.966	-7.945	2.191
*RD * FTI*	1.448	2.743	-2.558	10.845
*RD * DTP*	0.166	3.288	-5.079	16.096
JVPCT	0.488	0.290	0.000	0.951
INTEN	1.974	1.838	0.041	13.825
CAPINT	1.128	0.761	0.099	3.714

Total: 189 observations.

Since the book value of fixed assets used in constructing the variable *CAPINT* is not available in 1995, the empirical analysis is based on data from 1996 to 2004, which amounts to 189 observations. Table 1 provides a description of summary statistics of the constructed variables. As is usually found in patent data, the number of domestic patent applications in this analysis has more weight on the right tail than expected from usual Poisson distributions, which results in a much larger variance than their means. This indicates that patent counts are over-dispersed. To account for the over-dispersion of patent counts in estimation, I use the fixed effect negative binomial regression proposed by Hausman *et al.* (1984).

Table 2: Distribution of Patent Counts across Categories

Year	0	1-10	11-50	50-100	101-250	> 250
1995	2	11	5	2	1	0
1996	2	11	7	1	0	0
1997	2	9	6	4	0	0
1998	2	10	6	1	2	0
1999	4	8	5	2	2	0
2000	2	9	5	3	2	0
2001	3	8	6	3	1	0
2002	4	5	6	3	3	0
2003	4	6	6	2	2	1
2004	0	4	5	1	8	3

Table 2 demonstrates the distribution of patent application counts in different years. While aggregated at sector level, the patent applications filed by Chinese hi-tech firms are rather limited. Before 2001, more than half of the sectors had annual total patent applications of no more than ten, although afterwards firms in more regions took out more than that number annually. This indicates that innovation capability in Chinese domestic firms is at a very low level in terms of patenting.

4. Results and Discussions

Table 3 reports the results from the estimation, based on various model specifications. First, I consider a simple case where only two sources of knowledge stocks (*RD* and *FTI*) are included (column 1). It can be clearly seen that only in-house R&D contributes significantly to the introduction of patents. Although one might expect *FTI* to have a similar effect on innovation, the coefficient of *FTI* is insignificant although positive, suggesting that the impact of *FTI* on innovation is not as important as expected. When the term *DTP* is included, its estimated coefficient is found to be significantly positive (column 2). The likelihood ratio test shows that the model specification including the term *DTP* is preferred to the one in column 1, indicating that the impact of acquired domestic knowledge is important to patenting. Furthermore, the model including the interaction term *(RD*FTI)*, the result of which is reported in column 3, is found to be preferred to the one listed in column 2. In this case, the estimated coefficient of the interaction term is significantly positive, indicating that positive leverage can be gained by firms investing in both in-house R&D and FTI.

Table 3: Model Selections

Coefficient	Fixed effect				Random effect
	(1)	(2)	(3)	(4)	(5)
RD	0.475**	0.491**	0.345**	0.168	0.482**
	(0.126)	(0.122)	(0.130)	(0.198)	(0.113)
FTI	0.123	-0.085	-0.123	-0.157	-0.058
	(0.075)	(0.100)	(0.099)	(0.104)	(0.092)
DTP		0.268**	0.342**	0.363**	0.268**
		(0.093)	(0.100)	(0.107)	(0.092)
*RD*FTI*			0.124**	0.190**	0.086**
			(0.046)	(0.073)	(0.040)
*RD*DTP*				-0.091	
				(0.076)	
JVPCT	-0.502	0.210	0.225	0.168	0.363
	(0.455)	(0.496)	(0.498)	(0.511)	(0.416)
INTEN	-0.208**	-0.218**	-0.189**	-0.184**	-0.201**
	(0.050)	(0.048)	(0.050)	(0.050)	(0.049)
CAPIT	0.111	0.234**	0.214**	0.214*	0.097
	(0.124)	(0.113)	(0.109)	(0.116)	(0.118)
Log-likelihood	-596.27	-591.97	-588.54	-587.80	-725.27
No. of observations	189	189	189	189	189
No. of sectors	21	21	21	21	21

Standard errors in parentheses; ** p < 0.05, * p < 0.1; coefficients for constant terms and year dummies not reported for brevity

To examine whether a similar leverage effect exists between in-house R&D and DTP, one more interaction term *RD*DTP* was added to the model specification (1) (column 4). In this specification, the estimated coefficients of both *RD* and *RD*FTI* still remain significantly positive, while the coefficient of *RD*DTP* is not significant statistically.

Surprisingly, the coefficient of R&D knowledge stock is now insignificant. This is probably because of multicollinearity among explanatory variables. In this case, the mean and maximum variance inflation factor (VIF) values are 4.14 and 8.25, respectively. Both are larger than the common cut-off value of four. The likelihood ratio test suggests that this model is not preferred to the model reported in column 3. When the interaction term *RD*DTP* is added to the model reported in columns 1 and 2, the likelihood ratio tests always favour the model without the interaction term. Both tests suggest that no important leverage effect can be found between R&D and DTP. Thus, the model specification (3) is the most preferred among all specifications. In the model specification of column 3, the mean and maximum VIF values are 2.27 and 3.83, respectively, suggesting that multicollinearity is not a serious issue in this case. As an additional check, the results in column 3 are estimated from a random effect negative binomial specification, which are very similar to those reported in the preferred model. From these findings, one can conclude that absorptive capacity is more crucial for assimilating foreign technology than for exploiting domestic technology.

Table 4: Robustness Check

(g, δ)	**(5%, 5%)**	**(35%, 5%)**	**(5%, 35%)**	**(35%, 35%)**
	(1)	**(2)**	**(3)**	**(4)**
RD	0.168	0.335**	0.501**	0.498**
	(0.159)	(0.139)	(0.117)	(0.121)
FTI	-0.325**	-0.128	0.001	0.032
	(0.106)	(0.102)	(0.090)	(0.091)
DTP	0.470**	0.344**	0.199**	0.170**
	(0.105)	(0.101)	(0.082)	(0.080)
*RD*FTI*	0.131**	0.090**	0.089*	0.083*
	(0.044)	(0.038)	(0.046)	(0.046)
JVPCT	0.539	0.286	-0.029	-0.113
	(0.488)	(0.499)	(0.513)	(0.517)
INTEN	-0.185**	-0.199**	-0.196**	-0.196**
	(0.049)	(0.050)	(0.051)	(0.052)
CAPIT	0.220**	0.205*	0.207*	0.187
	(0.103)	(0.112)	(0.116)	(0.119)
No. of observations	189	189	189	189
No. of sectors	21	21	21	21

Standard errors in parentheses; ** $p < 0.05$, * $p < 0.1$; coefficients for constant terms and year dummies not reported for brevity

It may be wondered whether the way that three knowledge stock variables are constructed have any detectable impact on the estimated results, since they were computed from an assumed growth rate g and depreciation rate δ. To check for the robustness of these results, Table 4 lists four groups of results estimated from the preferred model with knowledge stock variables constructed from different combinations of g and δ. These combinations reflect a possible range of g and δ, that is, from five to 35 per cent. These four groups of results are reasonably similar to those in the preferred model in column 3 of Table 3, although the magnitude of estimated coefficients varies somewhat. Where both g and δ are set at five per cent, the direct effect of FTI knowledge is even significantly negative, which further strengthens the argument that FTI knowledge, itself, does not promote innovation in domestic firms.

From the econometric analysis, it is evident that investing in in-house R&D and DTP can facilitate directly an indigenous firm's introduction of innovations. Although this does not hold true for knowledge obtained through FTI, the findings do reveal that firms can take advantage of the leverage effect through in-house R&D. This result provides evidence supporting Cohen and Levinthal's (1990) argument of internal absorptive capacity. It is consistent with the results reported in Liu and White (1997) but contrasting to Liu and Buck (2007), which found that the significance of FTI is independent of domestic firms' absorptive capacity. The reason is probably because the latter study used new product sales as a measure of innovation, which overestimates the rate of innovation, given the argument made in last section.

Surprisingly, in all model specifications, the coefficients of *JVPCT* are statistically insignificant, showing no detectable impact of the presence of foreign firms on indigenous innovation of domestic firms. One can claim two opposing effects of the presence of foreign firms in local markets on innovation in domestic firms. One the one hand, competitive pressure from market penetration of foreign firms influences domestic firms to patent more actively and build their own competencies. On the other hand, relative technological advantage in foreign firms and strong intellectual property rights protection regime lock domestic firms in a low technology trap. Moreover, the large technological gap may also constrain learning in domestic firms. Considering the weak technological capability in most Chinese indigenous firms in the early period and that domestic patents represent new-to-the-country or new-to-the-world inventions, this finding is understandable.

Table 5: Sub-sample Regressions

	1996-2000	2001-04	Low-R&D sectors	High-R&D sectors	Export
	(1)	(2)	(3)	(4)	(5)
RD	-0.401	0.533*	0.216	0.572**	0.381**
	(0.246)	(0.280)	(0.199)	(0.242)	(0.146)
FTI	0.407**	-0.336	-0.227	0.210	-0.122
	(0.155)	(0.270)	(0.157)	(0.164)	(0.122)
DTP	0.215	0.514**	0.576**	-0.041	0.384**
	(0.165)	(0.260)	(0.133)	(0.215)	(0.124)
*RD*FTI*	0.286**	0.015	0.136**	0.211*	0.102*
	(0.086)	(0.085)	(0.060)	(0.109)	(0.052)
JVPCT	-1.800**	0.361	0.391	0.490	0.387
	(0.906)	(0.721)	(1.099)	(0.921)	(0.577)
INTEN	0.018	-0.274**	-0.147	-0.172**	-0.200**
	(0.072)	(0.096)	(0.110)	(0.071)	(0.058)
CAPIT	-0.312	0.389**	0.347**	0.074	0.265**
	(0.253)	(0.167)	(0.128)	(0.214)	(0.113)
EXSHARE_1					-0.122
					(0.965)
No. of observations	84	105	99	90	147
No. of sectors	21	21	11	10	21

Standard errors n parentheses; ** $p < 0.05$, * $p < 0.1$; coefficients for constant terms and year dummies not reported for brevity

To investigate whether this reasoning is justifiable and examine how the learning and innovation pattern in Chinese firms has evolved, an analysis based on two sub-samples was conducted. The first sample covered the period from 1996 to 2000 and the second from 2001 to 2004. The year 2001 was used as the dividing line for two reasons. First, Chinese patent law was amended in a way favourable to patent applicants and became effective as of July 2001. Secondly, China's accession to the World Trade Organization took place in 2001, committing the country to stringent compliance with international intellectual property rights (IPR) laws. These changes might have given Chinese domestic firms an incentive to take out more patents than before. Estimated results for the two sub-samples are in columns (1) and (2) of Table 5.

Both the direct impact of FTI knowledge and leverage effect between in-house R&D and FTI are positively significant in the early period, while neither of them is in the later period, suggesting that technological knowledge acquired from FTI probably has a favourable role in the early development stage of Chinese firms. Looking at the impact of both in-house R&D and DTP knowledge stocks, they are statistically significant in the later period but not in the early period. This substantiates the hypothesis that the learning and innovation mode has evolved as Chinese firms have become more technologically capable. In the early stage, innovation in indigenous firms relied more on assimilating foreign technologies. In the late period, however, generating new knowledge through in-house R&D began to emerge as a new mode of innovation. Findings based on two sub-samples suggest that the presence of foreign firms had a significantly unfavourable effect on domestic firms' innovation in the early period, while its effect disappeared in the later period. This is consistent with the above reasoning.

Among all model specifications in Tables 3 and 4, the estimated coefficients of *INTEN* are significantly negative, indicating that, in those rapidly evolving industries requiring a large amount of R&D commitment, indigenous firms have a relative disadvantage in innovation. It could be speculated that the estimated relationship between acquired knowledge and innovation varies across sectors. In other words, different sectors may have different learning and innovation patterns. Although a careful analysis of this issue is not possible due to the limitation of data availability, separated regressions based on sub-samples can provide some insights. Based on the sector level R&D intensity in 2004 (Table A1 in the appendix), the whole sample was divided into two groups. The first high-R&D group includes the top 11 sectors in terms of R&D intensity. The remaining ten are classified into the low-R&D group.

The breakdown analysis of these two sub-samples reveals several very interesting points (columns 3 and 4 in Table 5). First, the effect of in-house R&D on innovation is found to be much more prominent in the high-R&D group than in the low-R&D sub-sample. In the latter, the coefficient of R&D is not even statistically significant. Secondly, technological knowledge acquired from other domestic sources does not seem to be a significant factor contributing to the innovation of domestic firms in high-R&D sectors, although it does play an important role in innovation for firms in low-R&D sectors. This is consistent with the observation that Chinese universities, research institutes and innovating firms are often incapable of developing frontier technology knowledge in rapidly evolving and high-R&D sectors (Liu and White, 2001). Thirdly, although not significant, the direct impact of FTI knowledge is negative in low- and positive in high-R&D sectors, indicating that this is probably the result of the technological gap. Once again, the leverage effect between the two types of knowledge generated from R&D and FTI is found to be significant in both sector groups. These findings together suggest the existence of different learning and innovation patterns in different sectors. Specifically, in high-R&D sectors, domestic firms are more dependent on in-house R&D than their counterparts in the low-R&D group. To some extent, their innovation has to be self-reliant. By contrast, firms in the low-R&D group can innovate by drawing upon acquired external technology. In this sense, they innovate by imitation. In both sets of results, no evidence is found to support a direct impact of foreign technology on innovation. However, absorptive capacity is still essential for indigenous firms to utilize effectively foreign knowledge, no matter in which sectors they are.

In an effort to measure the impact of export on domestic firms' innovation performance, a new variable representing their exposure to international markets was incorporated into the preferred model specification. The variable, *EXSHARE*, is measured by exported share of total output value. To avoid potential endogeneity, its lagged value was used. Estimated results from this specification suggest that there is no detectable impact of export-led technology learning on innovation (column 5 in Table 5), which is contrary to the results reported in Liu and Buck (2006). Use of different measures of innovation may be one reason underlying these contrasting findings.

Finally, the estimated coefficient *CAPINT* is significantly positive in the preferred model, suggesting that the capital intensity of a sector is favourable to domestic firms' innovation in Chinese hi-tech industries. Higher capital intensity means a higher entry barrier and less competitive market structure. Firms in such a sector will be able to appropriate their innovation benefit more effectively and, therefore, have a stronger incentive to innovate. In this sense, the result is intuitive and justifiable.

5. Conclusions and Implications

In this paper, I empirically examined the effect of three types of investment in acquiring technological knowledge (in-house R&D, FTI and DTP) on Chinese indigenous firms' innovation capacity in 21 hi-tech sectors. Taking domestic patent applications as a measure of innovation output and the four-digit SIC sector as the unit of analysis, I estimated a sector-level knowledge production function with the fixed effect negative binomial count model technique. The data were constructed from a panel of 21 sectors from 1995 to 2004, which were drawn from recent sector level statistics published by CNBS.

Based on the estimated results, a number of findings are revealing. First, FTI knowledge alone does not effectively promote the innovation of domestic firms in terms of patents, although its contribution is prominent in the early development stage of Chinese hi-tech industries. A significant leverage effect between in-house R&D and FTI was apparent, which is consistent with the finding reported in Liu and White (1997) and provides empirical evidence for Cohen and Levinthal's argument for absorptive capacity. This implies that purchase of foreign technology alone is not conducive to a firm's innovation performance unless it is coupled with investment in R&D. From a strategic perspective, firms can better use foreign technology by, first, enhancing their absorptive capacity, which can be gained through their own R&D activities. Secondly, as absorptive capacity increases in Chinese firms, the learning and innovation effects of R&D have evolved. In-house R&D is now playing a dominant role in innovation, suggesting that a policy encouraging R&D investment is now preferable. Thirdly, the mode of learning and innovation varies between sectors. Firms in high-R&D sectors innovate on a self-reliant basis. They rely more on in-house R&D than on external technology for enhancement of their innovation capacity. By contrast, firms in low-R&D sectors are more likely to innovate by imitation. These findings imply that one catching-up strategy does not suit all industries. Different patterns of learning and innovation between industries call for distinct innovation strategies.

In interpreting findings reported in this analysis, several caveats call for attention. One limitation is associated with measurement of innovation output and construction of knowledge stocks. In particular, knowledge generated from different sources may depreciate at different rates, which will inevitably complicate analysis. In addition, use of sector as the unit of analysis leads to a rather small sample, for which small sample bias is a possible concern. Furthermore, issues examined in this analysis are better investigated at firm level. All of these issues are warrant further research.

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Appendix:

Table A1: 4-digit Chinese SIC Sectors Included in the Sample

Industries and sectors	R&D intensity in 2004 (%)
Medical and pharmaceutical products	
Chemical pharmaceuticals	1.40
Traditional Chinese Medicines	1.41
Biologicals	2.39
Aircraft and spacecraft	4.85
Aircraft	13.82
Spacecraft	
Electronics and telecommunication equipment	
Telecommunications transmission units	2.92
Telecommunications exchange units	8.01
Telecommunications terminal Units	0.63
Radar and peripherals	3.69
Broadcast and television	1.93
Electronic vacuum	1.57
Semiconductor separated parts	1.73
Integrated circuits	1.23
Electronic components	0.76
Household audio-visuals	1.25
Other electronics	0.54
Computers and office equipment	
Computers	0.46
Peripherals	0.47
Office	0.49
Medical equipment and meters	
Medical and instruments	1.39
Instruments and meters	1.86

Source: Calculated from NBS China (2002-2005).

Printed in Austria
V.08-58246—December 2008—200

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