Research Policy 37 (2008) 1465–1479

Contents lists available at ScienceDirect

Research Policy

journal homepage: www.elsevier.com/locate/respol

China's national innovative capacity

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ARTICLE INFO

Article history:
Received 3 September 2007
Received in revised form 20 May 2008
Accepted 2 July 2008
Available online 9 August 2008

Keywords:
China
National innovative capacity
Innovation performance
Patents

ABSTRACT

China is transforming itself into the workshop of the world, building an export-oriented national production system linked by global value chains to the world's leading economies. But to what extent is it laying the foundations for moving from imitation to innovation? In this first study of China's national innovative capacity, we extend earlier work conducted on the East Asian Tiger economies, and bring it up to the year 2005. We demonstrate a surge in patenting activity by Chinese firms and organizations since 2001, and analyze the drivers behind this, as well as the quality characteristics of the patenting – in terms of intensity, impact and links with the science base. We have some striking findings to report, including the strong role played by universities in the building of China's national innovative capacity over the last 15 years, and the puzzling apparent lack of contribution of the public sector in reinforcing China's national innovative capacity. On the latter point we suggest that the role of public sector institutions has been mixed, and only exerts its effects after reforms streamlined the system and brought many of the institutions into the private sector.

1. Introduction

China has caught the world's imagination, as it powers forward in an industrial transformation larger in scale and scope than ever before witnessed. The measures of China's transformation – from exceptional GDP growth rates and growth rates per capita, through investment levels that are enhanced through large flows of foreign direct investment, to levels of exports that now rank China as the world's number three trading nation, and soon to be number one – all these capture at the macro-scale the astonishing progress of this 21st century industrial giant. When combined with a micro perspective, which examines the rise of Chinese firms to become world players – from Haier in household goods, or Lenovo in IT and PCs, or Huawei in telecomm, or the Konka group in consumer electronics, not to mention Sinopec or CNOOC as global energy giants – then it becomes clear that there is a depth and breadth to China's manufacturing industry and its infrastructure underpinning that has made it the 'workshop of the world'.

China's undoubted gains in production and trade have been achieved through following a latecomer strategy – by accessing and putting to use the world's stock of technological knowledge with cheaper costs, and at a greater scale, than can be managed by incumbents. The latecomer always has to fashion entry strategies that mesh with, or complement, the prevailing strategies of the incumbents. In China's case its rise as production powerhouse has coincided with the trend towards outsourcing, creating opportunities that firms in China, and in wider East Asia, have been quick to seize, creating global value chains that are now one of the principal drivers of globalization.

As the latecomer approaches the technological frontier, so its strategies have to shift from imitation to innovation (Kim, 1997). This has been the case for all of the successful

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doi:10.1016/j.respol.2008.07.003

East Asian Tiger economies – for Japan first, then for Taiwan, Korea and Singapore – and now for China. Our question is: to what extent is China laying the foundations for future innovative capacity? Is it likely to stay stuck in catch-up mode as a perpetual imitator, or can it build its absorptive capacity to the point that it can sustain genuine innovation? To what extent is it building the elements of sustainable innovative capacity?

Our earlier study of innovative capacity in East Asia attempted to answer this question for the case of the Asian Tigers. Building on earlier work in innovative capacity and in particular on the framework for innovative capacity developed by Furman et al. (2002) for the OECD countries, Hu and Mathews (2005) replicated and extended this work to five East Asian economies – Korea, Taiwan, Singapore, Hong Kong and China – to assess to what extent they had been able to build the elements of innovative capacity, measured in terms of patenting rates at the USPTO.[2] Taking the study up to the year 2000, Hu and Mathews (2005) found that the East Asian Tigers (largely Korea and Taiwan) were more focused in their innovative capacity than the advanced OECD countries, in keeping with their latecomer strategies of concentrating their meagre resources on certain targeted activities and industries. We also found that the East Asian Tigers had made strong use of Public Research Institutes (PRIs) in guiding and focusing their efforts at technological catch-up – a feature not brought out in studies of the OECD countries. This made abundant sense, since micro-level studies of the role played by institutions such as ITRI for Taiwan or KIET for Korea made it clear that these PRIs had indeed been the architects of the technological catch-up strategies and had been responsible for acquiring the technologies that were then diffused rapidly across to the private sector (Lee, 2005).

What about China? In our earlier study, that took the story up to the year 2000, China hardly figured as a patenting player at all, and the drivers of national innovative capacity scarcely registered as having significant effects. Hence our interest in seeing to what extent the country's innovative capacity has been enhanced since then, and in analyzing the patenting activities as a guide to the overall architecture of an innovation system and its depth in terms of technological knowledge.

This present study is concerned with China itself, and is formulated as an extension of earlier work on East Asia that took the story up to the year 2000 (Hu and Mathews, 2005). This present study takes the story for China forward to the year 2005, and thus captures a half decade of patenting activity at the USPTO that – as we shall demonstrate – has already begun to create an intellectual production system that stands comparison with the physical production system that holds the world in awe. We extend our study of the East Asian Tigers also in the sense that we analyze patenting activity utilizing several tools that add a dimension of quality to the purely quantitative measures used in earlier studies – measures such as patenting intensity, patenting impact (in terms of forward citations), the depth of absorptive capacity (in terms of backward citations), cycle time, R&D cost per patent, and links with the science base (measured by patent citation to the scientific literature). This is the first study, we believe, that has examined China's national innovative capacity utilizing such a range of tools.

We are surprised at our findings, to be elaborated in what follows. We find that China shares many of the characteristics of the latecomer East Asian Tigers which it so clearly views as models for its own development. But it also has some defining characteristics of its own. One principal difference is that China exhibits a much larger reliance on universities as sources of innovative activity and of enterprises spun-off from universities and Academies which are themselves sources of further innovative activity. Another major difference is that the sprawling public sector in China has so far played less of a role in building China's innovative activity than would be expected, based on earlier East Asian experience. We attempt an explanation for both these interesting findings that have been thrown up by our analysis.

We begin by recalling the features of our earlier investigation of national innovative capacity (NIC) in East Asia, bringing the story of patenting rates up to the year 2005. We then outline the concept of NIC that we shall use in our analysis of China, and the details of the methodology to be employed. We then proceed to our analysis, conducted in two stages – the first as an extension of our East Asian NIC analysis to the case of China, taken up to the year 2005, then followed in a second stage by a closer examination of China's patenting activities at the USPTO, in terms of the quality and impact of the patents granted. We use this analysis to shed light on the somewhat surprising findings generated by our analysis of the drivers of China's NIC, particularly in relation to the role of universities and the role of PRIs.

2. National innovative capacity in East Asian and in China

National innovative capacity (NIC) may be broadly defined as the institutional potential of a country to sustain innovation, which has been investigated by numerous scholars, at least since Suarez-Villa (1990) formulated a clear definition of the concept and a measure of it in terms of patenting rates. One of the clearest indications of innovation performance is the rate of take-up of patents issued by the US Patent and Trademarks Office (USPTO). Patents are widely recognized as providing a reliable and unbiased indication of the innovation effort being expended by a country (Griliches, 1990; Trajtenberg, 1990).

We therefore adopt the patenting activities by Chinese firms and organizations at the USPTO as a measure of China's national innovative capacity. We extend work pre-

[2] The concept of innovative capacity has been formulated by numerous scholars, including Suarez-Villa (1990) and Suarez-Villa and Hasnath (1993). Porter and his collaborators adopted this notion and implemented it in a fashion that links innovative capacity to a country's knowledge production function, and applied it to the patenting record of OECD countries (Furman et al., 2002). Hu and Mathews (2005) took this methodology and applied and extended it to the case of the five East Asian Tiger economies, looking for points of consistency with innovative capacity as demonstrated in advanced OECD countries and points of difference in order to demonstrate the distinctiveness of latecomer strategies being pursued by the East Asian Tigers.

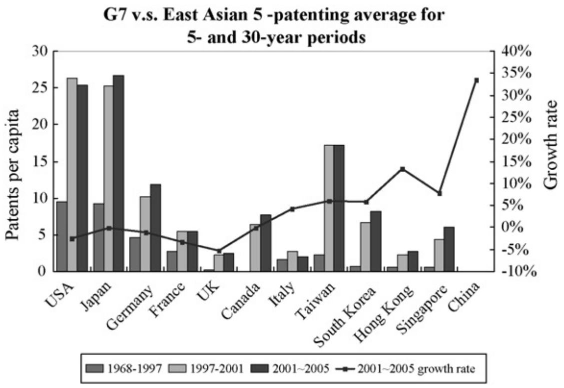

Fig. 1. *Source*: USPTO and compiled by the authors. *Note*: China's per capita patenting rate is too small to see on this Chart, given its very large population.

viously performed by Furman et al. (2002) for the 17 OECD countries, and by Hu and Mathews (2005) in applying their framework to the five East Asian Tiger economies. In the OECD countries studied by Furman et al. (2002) and others, more broadly-based variables are closely associated with variations in the rate of patenting, namely GDP per capita, total R&D expenditure, intellectual property protection, public expenditure on higher education and funding on academic R&D. In comparison, Hu and Mathews (2005) found that the process of building national innovation capacity in latecomer countries is comparable to that followed in more advanced countries, yet distinctive in ways that focus on four variables in particular, namely patent stocks, levels of R&D manpower, private R&D expenditure and specialization in high-tech industry along with Public R&D funding. The results are consistent with many works in East Asia and present the necessity of a strategic focus in building national innovative capacity in catching-up latecomer countries.

In this present study we update the Hu and Mathews (2005) study to encompass the years 2000–2005, and focus on a single country, namely China.[3] We engage in a two-step study, firstly employing the same framework and procedure for identifying the drivers of national innovative capacity, applied to China, and then analyzing the patenting record of firms and organizations at the USPTO to seek further insight into the way in which the elements of innovative capacity are being put in place in China.

In Fig. 1, we show how East Asian Tiger economies have been ramping up their patenting activities at the USPTO, both in terms of average growth rates and particularly in per capita terms. Taiwan has now achieved the status of third highest per capita patenting economy in the world since the mid-1990s, while Korea is just behind Germany in fifth place. China, starting from a low base, is growing faster

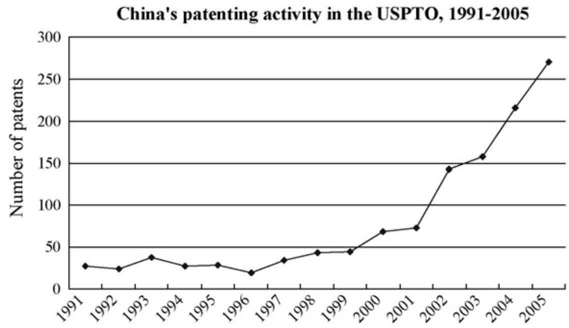

Fig. 2. *Source*: USPTO.

than others and holds the highest growth rate over the most recent period 2001–2005. As argued in Hu and Mathews (2005), we believe that the record of the East Asian Tiger economies throws up a mirror in which China can view its own likely future development, since it is following broadly similar latecomer strategies and building broadly similar catch-up institutions to those deployed in the East Asian tiger economies in the 1980s and 1990s.

We turn to China's patenting experience in Fig. 2, which shows the steep increase in the absolute numbers of patents granted to Chinese organizations at the USPTO, particularly since 2001 when China joined the WTO, and the increase in the rate of patenting activities. In Fig. 3 we show the respective contributions of six sectors identified above, namely public research institutes, universities, state-owned enterprises, private enterprises, foreign ventures and individuals, to bring out their different contributions in driving China's innovation capacity over the last decade and a half. This chart reveals how public research institutes have played an important role in patenting activities, but that patenting activity by the private sector has surged since 2001, which must indicate that the private sector was waiting for China to join the WTO (achieved in 2001) and had been holding back until that point. After 2001 it has clearly had greater confidence that international standards would be applied in the protection of intellectual property.

Finally, in Table 1 we identify the top organizations from China taking out patents at the USPTO. The prominent role played by PRIs from the chemical and petrochemical sector is striking, while Tsinghua University emerges as dominant within the university sector, and a handful of private sector

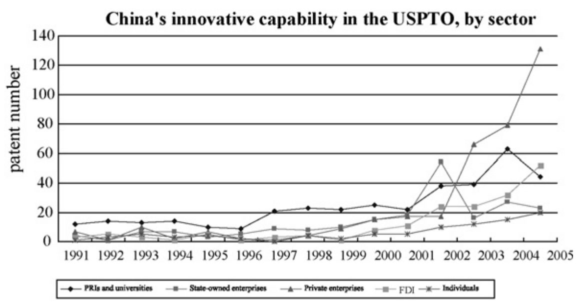

Fig. 3. *Source*: USPTO and compiled by the authors.

[3] It is certainly the case that China is a very much larger country than any of the East Asian Tiger economies, and therefore it might be suggested that a regional approach in analyzing China's NIC might be appropriate. Whatever the merits of this argument for future studies, at this early stage in the development of China's NIC, we hold that a national examination for China makes sense.

Table 1
China's top patentees, 1991–2005, by sectors

	1991–1995	1996–2000	2001–2005
PRI	Research Institute of Petroleum Processing (3)	1. Research Institute of Petroleum Processing (18) 2. Fushun Research Institute of Petroleum and Petrochemicals (4) 3. Shanghai Institute for Biochemistry, Chinese Academy of Sciences (4) 4. Dalian Institute of Chemical Physics (4)	1. Research Institute of Petroleum Processing (24) 2. Changchun Institute of Applied Chemistry (12) 3. Beijing Research Institute of Chemical Industry (10) 4. Fushun Research Institute of Petroleum (10)
University	Tsinghua University (4)	Tianjin University (5)	Tsinghua University (19)
State-owned	China Petro-Chemical Corporation (12)	China Petro-Chemical Corporation (37)	China Petro-Chemical Corporation (73)
Private sector			1. Huawei Technologies Co., Ltd. (14) 2. Semiconductor Manufacturing International (Shanghai) (10) 3. Xinjiang Shengsheng Co., Ltd. (7)
Foreign venture		Iskra Industry Co., Ltd. (JP) (3) Mitsui Norin Co., Ltd. (JP) (3)	1. SAE Magnetics (H.K.) Ltd. (38) 2. Headway Technologies (US), Inc. (23)

Source: USPTO. *Note*: (1) The number in the bracket represents the patent number granted by the USPTO. (2) For the years 1991–1995 and 1996–2000, only patent granted number greater (or equal) than 3 is listed; for the years 2001–2005, only patent granted number is greater (or equal) than 5 is listed.

firms such as Huawei in telecomm are revealed as significant patentees.

2.1. The role of universities and public research institutions (PRIs) in China

China's PRIs, supported by public R&D expenditure at both local and national levels at the earlier stage of economic development, constituted the backbone of the nation's innovation system. Two-thirds of the national R&D funding and personnel inputs ensured that PRIs have been the most prolific patentees amongst the six major players in China's economic development as shown in Fig. 3. Although Foreign Direct Investment (FDI) was attracted to China by the "Open Door Policy" and Deng Xiaoping's Southern Tour in 1992, foreign ventures did not become players in China's innovation system until the 2000s and ranked in second place in 2005, as shown in Fig. 3. Notably, the private sector emerged quickly and overtook the PRIs and other sectors to become China's premier patentee sector in the USPTO since 2003. Apart from reflecting enhanced absorptive capacity, the dramatic increase in innovative activity in the private sector (or at least in patenting activity) must be due in part to the fact that many of the PRIs have been transformed into private technology service enterprises as a result of government-inspired shifts and legislative enactments (NRCSTD, 2003). We shall demonstrate below the dramatic impact of these reforms of the PRI sector on patenting activities.

The role of universities in research and innovation is shaped by the national innovation system, as shown in the varied experiences of the West (Mowery and Rosenberg, 1993). In China, we find that the university sector's role in the country's innovation system has changed dramatically over the last decade. While public R&D support plays a critical role in Asian latecomer countries, in shaping and guiding the innovative activities of firms, the universities and PRIs have played a somewhat different and characteristic role in China's case, i.e. through university-run enterprises or PRI spin-offs (described as *forward engineering* by Lee (2005)). These university spin-off ventures which are invested in and wholly owned by universities, operated and owned jointly with other entities, or partially invested in by universities, have become a distinctive feature of China's innovation system (Xue, 2005; Wu, 2007a). This is reinforced by regional findings. In the last decade, three IT industry-based clusters, in Beijing, Shanghai, and Shenzhen, have emerged in China. The innovation drivers in the first two of these are universities and public research institutes, whereas in Shenzhen they seem to have made little or no contribution (Wu, 2007b; Chen and Kenny, 2007).

Typical universities- and PRIs-affiliated (URI) enterprises such as Lenovo, Founder and Stone Group have been widely discussed (China's Higher Education Committee, 2006; Lu, 2000; Xue, 2005). However, many more prominent examples have emerged in the 2000s. For example, Huawei Technology (China's premier telecommunications equipment producer) has emerged as the most prolific patentee in the USPTO since 2004, followed by Semiconductor Manufacturing International (Shanghai) Corporation (China's No. 1 and world's No. 4 semiconductor manufacturer), and Positec Power Tools (Suzhou) Corporation (China's premier power tool maker and very aggressive in international M&A activity (mainly to acquire branded marketing channels).[4] All of these firms are aligned with or diffused from PRIs or universities.

Since China's entry into WTO, universities and their affiliated technology parks are believed to play significant roles in contributing to the country's economic development (Chen and Kenney, 2007). By the end of 2002, the 44

[4] Positec Power Tools was established in 1988 as an export-oriented company; all its products are exported to the US, Europe and Japan. Following China's entry into the WTO in 2001, Positec has refocused on the importance of intellectual property rights, and has undertaken intensive foreign patenting activity in those advanced countries. By 2006, Positec had filed for 260 foreign patents and had been granted 119 overseas patents (Suzhou Industrial Park, www.sipac.gov.cn).

university-established science parks had attracted investment of RMB 29.7 billion, employed 100,000 persons in 1200 R&D centers, supported 5500 high-tech companies, incubated 2300 start-ups of which 920 have graduated and 29 been listed on the stock exchange (Zhou, 2003). As of 2004, no fewer than 52% of all URI-affiliated enterprises are in advanced technology fields which produced more than 80% of the total revenue (Ministry of Education, 2005).

Patents and patenting activities remain a central part of a nation's innovation system, and an extremely important aspect and signal of the health of the innovation process. Patenting by Chinese firms at the USPTO indicates a serious innovative intent, and hence provides us with a reliable foundation for measuring innovative capacity. While patenting systems have complex economic and legal characteristics, and the US system certainly exhibits some alarming characteristics today – e.g. a tendency amongst some firms to patent as a substitute for real innovation, and even as a block to innovation (Pisano, 2006) – nevertheless for latecomer countries that are looking to catch-up with the industrial leaders today a capacity to register innovative capacity in terms of patenting activity appears to be inescapable as a strategy for advance. The East Asian Tigers learnt this the hard way (by having to pay very high royalties for their high-tech successes) and as a result they are amongst the highest patentees on a per capita basis now in the world. It is a lesson that China seems to have absorbed, and it is now embarked on a growth and transformation of its innovation system that looks set to emulate its stellar performance in its production and trade system.

3. Methodology

This study utilizes two interactive statistical methods in order to clarify the drivers of China's evolving innovative capacity and patterns of development that have emerged over the past 15 years. The first stage of our analysis applies the East Asian NIC concept to China, in order to specifically examine the drivers of China's innovative capacity. The results are then elaborated in the second stage by examining China's innovation performance (i.e. patenting activity at the USPTO) through the lens of measures of the quality and intensity of patenting activities, utilizing three standard patenting indicators and five citation indicators as defined by the consulting organization ipIQ (formerly CHI Research).[5]

3.1. The concept of national innovative capacity

Given that changes in China's innovative capacity can only be discerned since the "Open Door Policy" was further confirmed in Deng Xiaoping's Southern Tour in the spring of 1992, the first stage of our analysis thus begins with data collection from the period 1991–2005, and focuses on the drivers of national innovative capacity as revealed in the East Asian work by Hu and Mathews (2005). In this work, public R&D expenditure emerges as a distinctive driver of innovation in latecomer countries.[6] The conceptual framework of this present study is mainly derived from the endogenous growth theory, and specifically the idea of the "knowledge production function" (Romer, 1990; Jones, 1995, 2002), in which the growth of new knowledge depends positively on the cumulative stock of knowledge and the amount of human capital engaged in R&D.

Three main sets of ideas underpin the notion of NIC. These are (1) *common innovation infrastructure*, where the variables are population (POP), each country's number of full-time-equivalent scientists and engineers (FTE S&E), total R&D expenditures (TOTAL R&D), GDP per capita, the country's openness to international trade and investment (OPENNESS), its regime for the protection of Intellectual Property Rights (IP), the strength of its antitrust law (ANTITRST), and the critical public variable R&D expenditure (PUBLIC R&D) which is found to play a prominent role in East Asian latecomer development; (2) *environment for innovation in industrial clusters*, where the variables are R&D expenditure in the private sector (PRIVATE R&D), and China's relative specialization in three important technological sectors (namely SPECIALISATION in chemicals, electrical and mechanical) in the USPTO; and (3) the *linkages between innovative infrastructure and cluster-specific innovation*, where the variables are universities R&D expenditure (UNIV R&D) and venture capital availability (VENTURE CAPITAL).[7] Except for the patenting data (from the USPTO), country's openness (OPENNESS), IP protection, ANTITRUST and VENTURE CAPITAL (from the *IMD's* Competitiveness Reports), all datasets are collected from China's Science and Technology Statistics and National Bureau of Statistics of China.

The equation to be estimated and analyzed in this study adopted a log–log formulation of the following kind:

$$L\grave{A}_{j,t} = \delta_{\mathrm{YEAR}}\mathrm{YEAR}_t + \delta_{\mathrm{country}}C_j + \delta_{\mathrm{INF}}LX^{\mathrm{INF}}_{j,t} + \delta_{\mathrm{CLUS}}LY^{\mathrm{CLUS}}_{j,t} + \delta_{\mathrm{LINK}}LZ^{\mathrm{LINK}}_{j,t} + \lambda LH^{A}_{j,t} + \varphi LA_{j,t} + \varepsilon_{j,t}$$

In the equation, L stands for the logarithm, $\grave{A}$ stands for the production of innovation, YEAR_t stands for year-specific technology shock, C_j for country-specific technology shock, H^A for human capital and financial resources as R&D inputs, A for cumulative technological sophistication, X^{INF} for common innovation infrastructure, Y^{CLUS} for cluster- specific environment for innovation, Z^{LINK} for the quality of linkages between innovation infrastructure and the environment of

[5] ipIQ (formerly CHI Research) is a leading Intellectual Property consulting firm, providing technology-oriented services, including IP-related industry surveys and reports to firms contemplating acquisitions. The company has formulated various measures of patenting quality, which we deploy through our own calculations in this study.

[6] The measure of national innovative capacity in the OECD countries did not include the public R&D expenditure in the work of Furman et al. (2002).

[7] The majority of China's manufacturing goods are exported to North America and the EU (either directly shipment or through East Asian transshipment effected in order to avoid the anti-dumping restrictions imposed by the advanced countries. This is one of the factors behind our choice to use patent data from the USPTO instead of from the EPO or JPO. In addition, important inventions, regardless of origin, are likely to be patented in the USPTO, especially for the East Asian latecomer countries which have close historical and economic ties with the US.

cluster- specific innovation, and finally ε for the sources of error.

A nation's ability to develop absorptive capacity relies heavily on previous investment experience. Investment in the early years allows them to make better technological choices and to exploit new opportunities (Cohen and Levinthal, 1990). Therefore, we employ GDP PER CAPITA and PATENT STOCK as dependent variables respectively because they reflect the potential and direct capacity to support knowledge accumulation.

3.2. Innovation performance indicators

One of the clearest indicators of innovation performance is the rate of take-up of patents issued by the USPTO, although the precise rate of technological innovation is inaccessible (Mansfield, 1986; Arundel and Kabla, 1998). To capture and reflect faithfully the evolving pattern of development for China's innovative capacity over the past 15 years, the empirical results derived from the first stage will be cross verified by careful analysis of citations of patents in the USPTO in the second stage. The dataset is thus divided into six sectors across three 5-year periods: 1991–1995; 1996–2000; and 2001–2005. The six sectors chosen are (1) universities; (2) public research institutes; (3) state-owned enterprises; (4) private enterprises; (5) foreign direct investment ventures; and (6) individuals. Our research methodology makes use of a computerized US patent database from the firm World Intellectual Property Search (WIPS). Patents are the most valuable form of information available for competitive analysis. Different indicators are being used to predict the value of a patent or any organization's strength. This study uses three standard patent indicators and five advanced citation indicators invented by ipIQ to analyze China's innovative capacity over the past 15 years. All indicators are calculated for the six particular sectors mentioned above, namely universities, public research institutes, state-owned enterprises, private enterprises, foreign affiliations and individuals.

The standard patent indicators utilized in this study are the number of patents, patent compound growth rate and patent intensity in each of the sectors. Since patents can vary enormously in their importance or value, simple patent counts are unlikely to capture the full force of the innovative output of the sectors (see, for example Trajtenberg, 1990; Jaffe et al., 1993; Jaffe and Trajtenberg, 2002). Thus the alternative is patent citations rate, which is recognized as a proxy reflecting the impact and depth of innovation activity. While research has established that highly cited patents represent economically and technically important inventions (e.g. Griliches, 1990; Narin, 1993), we use five patent citation indicators to evaluate innovative capability in the six sectors, as follows.

(1) Forward citation rate: A count of the citations received by a sector's patents from subsequent patents. This helps to evaluate the technological impact of patents. High citation counts are often associated with important inventions, ones that are fundamental to future inventions and may have more competitive advantages in that technological field.
(2) Backward citation rate: A count of the citations made reference by a sector's patents to prior patents. This helps to trace the source of innovation/knowledge as well as the developmental trajectory of innovation capability in the sectors.
(3) Average citation frequency: Since China is an emerging latecomer country with an unique economic and industrial development, this study also utilize average citation frequency in order to evaluate China's endogenous innovative capability in the past 25 years. Average citation frequency, comparable to Current Impact Index (CII), represents the average number of times in which a sector's previous 5 years of patents are cited in the current year in the USPTO; this shows how frequently they were used as the foundation for other inventions.
(4) Technology Cycle Time (TCT): Indicates speed of innovation or how fast the technology is turning over, defined as the median age of the patent cited on the front page of a patent document. The TCT is measured in years. This indicator can measure the pace of technological progress. Shorter cycle times reflect faster substitutions, indicating faster progress; while longer cycle times reflect slower substitutions, indicating slower progress (Narin, 1993).
(5) Science Linkage Indicators: The counts of patent references citing papers from the scientific literature. Increasingly, patents are citing non-patent documents as prior art, and many of these are papers in scientific journals. A high level of science linkage thus indicates that a patent is building on a technology base grounded in advances in science.[8]

4. China's national innovative capacity: analysis of the drivers

The descriptive statistics utilized in the analysis summarized the experience of China's innovation driving factors over the period 1991–2005 are listed in Table 2. The annual innovative output PATENT is defined as the number of Utility patents granted to Chinese assignees from a country by the USPTO. The main results are reported in Table 3, showing the variance of patenting with respect to two measures of knowledge stock, namely GDP per capita and accumulated patent stock. Each will be discussed in the next section.

4.1. GDP as knowledge stock

Table 3 shows the determinants of China's NIC by taking GDP per capita and accumulated patent stock respectively as proxies for knowledge stock. Given the size of the population in China, it is not surprising to find a negative contribution made by population (POP), while FTE S&T manpower makes a positive contribution to the knowl-

[8] Note that patent citation rates differ by technology and strictly speaking, comparisons should be made only within similar technology groups. However in China's case, given the low level of patenting at this stage and the large size of the country, we will overlook this issue and focus on comparisons of innovative activity across the six sectors.

Table 2
Descriptive statistics

	N	Minimum	Maximum	Mean	S.D.
PATENT	16	19	270	77.31	77.12
GDP	16	1492	5332	3260.13	1235.04
GDPPER	16	1.5	4.5	2.744	.932
PATSTOCK	16	194	1406	540.50	350.56
POP	16	1135185.0	1307555.0	1231082.8	55111.8
FTE S&T	16	565400	1211350	855006.25	191021.82
TOTALRD	16	10810	245000	79305.00	69582.91
PUBLICRD	16	3837	53470	24471.06	14453.19
OPENNESS	16	4.6	6.1	5.474	.407
IP	16	2.70	5.32	4.1675	.9420
ANTITRUS	16	4.04	6.33	4.8850	.7094
PRIVATRD	16	3993	167300	46182.75	49305.42
CHEMICAL	16	.22	.58	.3781	.1059
MECHANIC	16	.19	.50	.3762	9.337E-02
ELECTRIC	16	.13	.38	.2469	7.726E-02
UNIVRD	16	2980	24230	8651.25	6481.10
CAPITAL	16	1.95	5.34	4.2588	.8809
Valid N (listwise)	16				

Note: Total R&D = public R&D + private R&D + university R&D.

Table 3
GDP per capita/patent stock as knowledge stock

		Knowledge production function		Innovation infrastructure		National innovative capacity: including all variables	
		GDP per capita	Patent stock	GDP per capita	Patent stock	GDP per capita	Patent stock
Innovation infrastructure							
A	L Patent stock		1.256***		1.474		−3.610**
A	L GDP	0.872**		0.322**		0.071	
H^A	L POP	−1.456***		0.564**		1.054	
H^A	L FTE S&T	1.461***	0.085	−0.016	−0.024	−0.403	−0.677***
H^A	L Total R&D			0.535**	−0.315	0.746	0.452
X^{INF}	Public R&D			−0.339	0.033	−0.606	−2.551**
X^{INF}	Openness			0.036	−0.002	0.138	0.671**
X^{INF}	IP			−0.035	−0.167	−0.500*	−1.038***
X^{INF}	Antitrust			−0.038	0.018	0.196*	0.284***
Cluster-specific innovation environment							
Y^{CLUS}	Private R&D					−0.236	2.974**
Y^{CLUS}	$\text{Specialization}_{\text{chemical}}$					0.144	0.486**
Y^{CLUS}	$\text{Specialization}_{\text{mechanicall}}$					−0.746	0.024
Y^{CLUS}	$\text{Specialization}_{\text{electrical}}$					−0.417	−0.210***
Quality of linkages							
Z^{LINK}	University R&D					1.711**	2.766***
Z^{LINK}	Venture capital					−0.321	−0.843***
Controls							
Year fixed effects		Significant	Significant	Insignificant	Insignificant	Insignificant	Significant
R^2		0.913	0.984	0.997	0.99	0.998	0.999
Adjusted R^2		0.891	0.98	0.994	0.978	0.991	0.998
Number of observations		16	16	16	16	16	16

Note: $^*P < 0.1$, $^{**}P < 0.05$, $^{***}P < 0.01$.

edge production function. Moreover, China's lower base of industrial development and the fact that it has been focused on labour-intensive industries over the past 20 years allow GDP, population and total R&D expenditure to act as the most important drivers of innovation infrastructure and contribute to overall economic growth. When China's innovative system includes all interactive variables, university R&D leaps out as the most significant driver while the antitrust policy also exerts its influence on overall innovative capacity. Indeed, significant GDP growth in China is observed particularly from the mid-1990s when the universities began to focus on research for industrial needs (due to the large number of universities-run enterprises or spin-offs).[9] This forward engineering model generated by university R&D is attributed to China's weak innovation capability in the private sector (due to the separation between R&D and production activities under the Soviet model). The critical effect of the antitrust policy may be deduced from a series of reforms in the last decade encouraging mergers and restructuring of state-

[9] The accumulated number of university spin-offs reached 42,945 within 7 years between 1997 and 2004 (Xue, 2005).

owned enterprises and PRIs, many of which have now emerged as private firms (Wu, 2007a; Xue, 2005).

4.2. Patent stock as knowledge stock

When patent stock is taken as proxy for knowledge stock, as shown in Table 3, we find that accumulated patents become the key contributor to the knowledge production function, resulting from the importance of technological evolution on innovation. However, none of the innovation infrastructure elements explain innovative activity (in terms of patenting rate in the USPTO), implying that the main effect of building innovation infrastructure over the past 15 years is revealed more in reinforcing China's absorptive capacity (which is mostly reflected on its significant domestic economic growth) than in its innovation activity – by contrast with the case of the Asian *Tiger* economies where a relatively stronger absorptive capacity has been built during the observed period. When we include all variables in the model of China's innovative capacity, five variables become positive and significant in their influence on innovative capability, including international openness, antitrust policy, private R&D, specialization in the chemical sector, and university R&D. Amongst the five most influential drivers, private R&D and university R&D emerge as the two dominant factors. This provides evidence supporting the important roles of both private and university sectors in building China's national innovative capacity in the past 15 years.

4.3. Negative and insignificant factors

In contrast, there are six variables (patent stock, S&T researchers, public R&D, IP protection, specialization in electronics area and the availability of venture capital) that moderate the building of China's innovative capacity. The negative impact of patent stock may reflect the insufficiency of previous technological knowledge, as well as the inefficiency or misalignment of public R&D expenditure and the shortage of S&T manpower in the past 15 years. For example, two-thirds of total R&D expenditure was concentrated in the public sector before mid-1995 while the number of researchers per 10,000 employees in China was only 22 in 1999 – lower than in other East Asian economies like Taiwan (91.7) and in most of the more developed countries (National Bureau of Statistics, 2000; National Science Council, 2000).

It is no surprise that IP protection and venture capital exert a negative contribution, given China's latecomer status and relative paucity and strict regulations on financial resources. However, it is surprising to find that specialization in electronics – China's premier high-tech export product – exerts a negative influence on innovative capacity. In order to further examine the effect of $\text{Specialization}_{\text{electrical}}$, we test its variation and find that it turns into a positive driver only when the variables of IP protection together with international openness are both removed from the model. We interpret this to mean that while international openness (e.g. openness to FDI) helps to build China's endogenous growth, some external regulations (e.g. IP rules) may substantially offset China's innovative capacity, demonstrating a disconnect between upstream innovative activity and downstream market performance. Indeed, more than 70% of China's high-tech exports are still focused on processing with imported materials, in which innovation activity has to be less involved (China S&T Statistics, 2006).

When patent stock acts as knowledge stock, two interesting points emerge. First, OPENNESS does not exert its positive contribution (coefficient 0.671) until IP (negative coefficient −1.038) is added into the model – implying a close relationship between international openness (i.e. FDI) and IP protection. Second, while VENTURE CAPITAL, IP and FTE S&E all present as negative coefficients, the interactions between them essentially increases the overall significance of the model in building China's innovative capacity. These results imply that factor interactions and correlations exert differential effects at different stages in building national innovative capacity.

As stated above, we now wish to contrast these purely quantitative measures (patent counts) with some measures of the quality of patents secured, in terms of patent intensity, forward and backward citations and technology turnover. We now proceed to this aspect of our study.

5. China's qualitative patenting record at the USPTO

In order to investigate further our somewhat surprising result that China's public R&D does not seem to exercise a positive influence in building national innovative capacity, by contrast with the case of the East Asian Tiger economies (Hu and Mathews, 2005), we now proceed to examine the components of China's innovation activities in greater detail, to examine the development trajectory and technological performance of separate sectors, in terms of their patenting activities in the USPTO. As mentioned above, we analyze patenting activities across six categories, namely universities, PRIs, SOEs, private firms, foreign-owned firms, and individuals.

5.1. Patent intensity

Fig. 4 demonstrates China's innovative efficiency or patent intensity, measured as the average R&D expenditure per patent granted from the USPTO, across the six sectors.

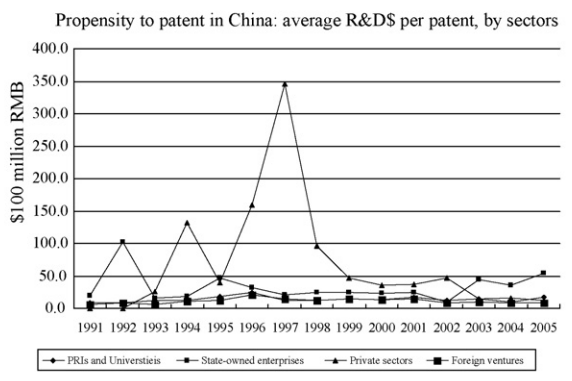

Fig. 4. *Source*: USPTO, China's S&T indicators (various years) and complied by the authors.

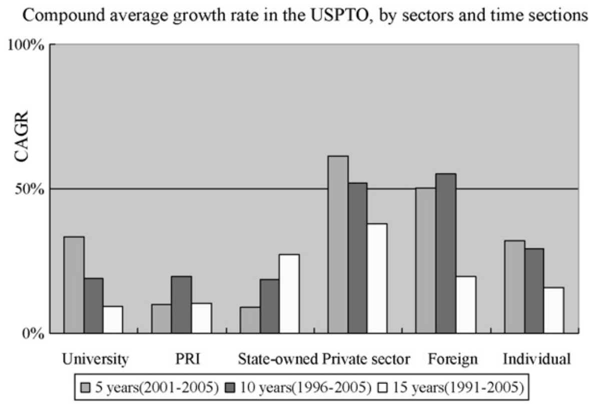

Fig. 5. *Source*: USPTO search and complied by the authors.

Not surprisingly, foreign ventures exhibit the highest levels of innovative efficiency, followed by the PRIs and universities; this reflects the essential role of foreign technology as well as the suggestion of top-down technological diffusion in China (Chen and Kenney, 2007). It is also worth noting that while the private sector exerts a critical influence on innovative capacity and efficiency in the recent period, the innovative efficiency in the state-owned enterprises has diminished; this could correspond to the fact that between one-third and two-thirds of state-owned enterprises are running at a loss, even though efficiency has been somewhat improved in recent years (Sun and Tong, 2003; Xue, 1997).[10]

5.2. Patent growth rate

Fig. 5 compares China's compound average growth rates (CAGR) in patenting, by sectors and by time periods, taking the period from 1991 to 2005 in three slices corresponding to 5, 10 and 15 years respectively. First we note that universities' patenting CAGR has steadily increased over each time period, while that of SOEs has declined and that of the PRIs has fluctuated. This would support our earlier finding in the analysis of China's NIC that universities have exercised an increasingly important role, relative to that played by PRIs and SOEs. By contrast, the absolute and relative improvement in the contribution of the private sector, and of foreign-owned firms, is striking – rising to a CAGR of 61.3% for the most recent 5-year period, and to 50% for the foreign-owned sector. It is also worth noting that individuals continue to figure prominently, a feature which is characteristic of East Asia as a whole (and may be attributed to the dominance of small and medium-sized enterprises in patenting activity, and the need for owners to vest patents in themselves rather than in firms which may be wound up at any time).

[10] The corporate governance or managerial ownership in China may be one of the primary reasons for the unsuccessful reform of state-owned enterprises. While managers in state-owned enterprises are selected by the government, conflicting goals and fixed serving terms greatly reduce the incentives for pursuing profit and innovation (Li et al., 2007; Liu, 2001).

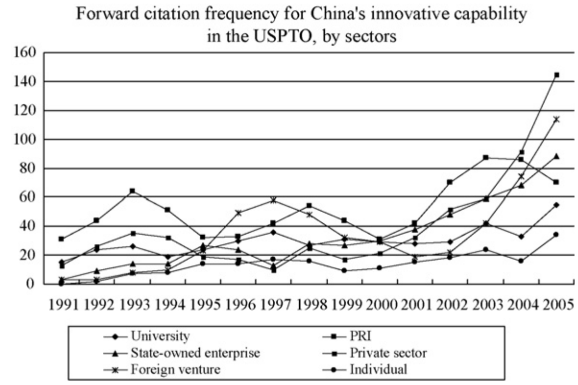

Fig. 6. *Source*: USPTO search and complied by the authors.

5.3. Forward citation frequency

Fig. 6 demonstrates China's forward citation frequency in each sector in the USPTO. In order to avoid truncation problem of citation counts, the citation frequency in this study represents how often the organization's patents from the previous 5 years are cited as prior art in that year, in which the importance of innovations in the sectors can be evaluated. The results presented in Fig. 6 reveal once again the importance of PRIs at an earlier stage of China's economic development as well as the dominant role in the most recent period played by the private sector and by foreign-owned firms. However, the significant increase in citation frequency across all six sectors is particularly to be noted since the year 2001 – further reinforcing the significance of China's entry into the WTO in that year.

5.4. Backward citation counts

Backward patent citations are references made to prior art in a patent application. Thus, these citations can trace the source of innovation/knowledge as well as the developmental trajectory of innovation capability. The higher backward citation rate may represent the higher dependency and stronger absorptive capacity from previous innovations (Rothaermel and Hill, 2005; Cohen and Levinthal, 1989). In Fig. 7, the evolution of China's innova-

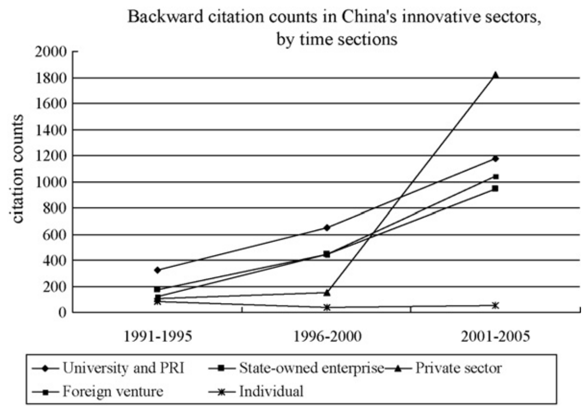

Fig. 7. *Source*: USPTO search and complied by the authors.

tive capacity is shown in the increasing backward citation counts in the six sectors over the years 1991–2005, in which the PRIs and universities play the major role in building China's absorptive capacity during the 1990s, before the private sector emerged as primary driver of the build-up in absorptive capacity since the year 2001. It is interesting to note that the US and Japan are China's major knowledge sources for the past 15 years, as demonstrated in Table 4, accounting for more than 50% and 20% respectively of China's backward citation rates. It is worth noting that during 2001–2005, the knowledge sources for the private sector became more diverse than for other sectors, implying an enhanced level of absorptive capacity in the private sector. The dependence on US and Japanese firms as knowledge sources in China's patenting activities also indicates trouble ahead as royalty demands start to be levied.

5.5. Technology cycle time (TCT)

TCT uses patent citations to indicate the age of the innovations on which a new innovation is based; as such, it is a valid measure of the pace of technological progress in a specific technology. Although TCT varies within and between industries and technologies, this study focuses on exploring China's innovative capacity across the six major sectors we have been considering. After the TCT values were calculated for each year under consideration, we expected to find a correlation between the TCT and the number of patents per year because, logically, one would expect to find little or no increase in the number of patents associated with a technology experiencing a slowing pace of technological progress. Four sectors, namely the universities, PRI, SOEs and private sector, were chosen and their TCT displayed in a time series as shown in Fig. 8a–d.

To take the university sector first (Fig. 8a), we see that the number of patents and TCT remained constant over the years 1991 to 2000, and then the number of patents taken out increases while the TCT declines from around 12 years to 6 years – indicating a rapid pace of progress. We therefore suggest that China's universities have passed through the catch-up and internalization stage of innovation from the period 1991–2000 and have been transformed into the stage of full innovation since 2001. This tendency is even clearer for the private sector (Fig. 8b), where the patenting rate increases sharply from the year 2003, while the TCT continues a secular decline to around 6 years. By contrast, the patenting rates and TCT values for PRIs (Fig. 8c) and for SOEs (Fig. 8d) shows a less pronounced increase in patenting rates in the years since 2001 (or even a decline as in the PRIs) while the TCT hovers around a value of 10 years or more – the longer cycle time indicating a slower rate of technological progress. This provides further evidence of the important role played by universities and the private sector in China's recent NIC.

5.6. Relationship between TCT and science linkage

In order to further explore the innovation quality of the six sectors and particularly that of public R&D in building China's national innovative capacity, we now turn to examine the strength of the innovations based on advances

Table 4
Backward citation rate of China's innovation activity in the USPTO, by sectors and time sections

	PRI and university			State-owned			Private sector			Foreign venture			Individual		
	1991–1995	1996–2000	2001–2005	1991–1996	1996–2001	2001–2005	1991–1995	1995–2000	2001–2005	1991–1995	1996–2000	2001–2005	1991–1995	1996–2000	2001–2005
US	205(64%)	394(63%)	636(57%)	118(72%)	286(68%)	524(59%)	56(55%)	69(49%)	907(51%)	74(65%)	240(55%)	522(52%)	31(67%)	32(63%)	93(44%)
Japan	68(21%)	77(12%)	176(16%)	14(9%)	60(14%)	126(14%)	23(23%)	43(30%)	365(20%)	28(25%)	117(27%)	276(27%)			42(20%)
Germany	17(5%)	36(6%)	64(6%)		23(6%)	40(4%)			93(5%)			52(5%)			
France		40(6%)	72(6%)	10(6%)	15(4%)	63(7%)			51(3%)						
China (self-citation)		17(3%)	46(4%)		12(3%)	34(4%)			23(1%)						
Canada			24(2%)						35(2%)						
Taiwan									62(3%)		20(5%)	16(2%)			
Korea									36(2%)		15(3%)	26(3%)			
Hong Kong									27(2%)			17(2%)			
Great British									26(1%)						
Italy									24(1%)						
Beligum									21(1%)						
Others	28(9%)	61(10%)	98(9%)	21(13%)	22(5%)	103(12%)	23(23%)	30(21%)	115(6%)	11(10%)	82(19%)	97(10%)	15(33%)	19(37%)	77(36%)
Total citing counts	318(100%)	625(100%)	1116(100%)	163(100%)	418(100%)	890(100%)	102(100%)	142(100%)	1785(100%)	113(100%)	439(100%)	1006(100%)	46(100%)	51(100%)	212(100%)

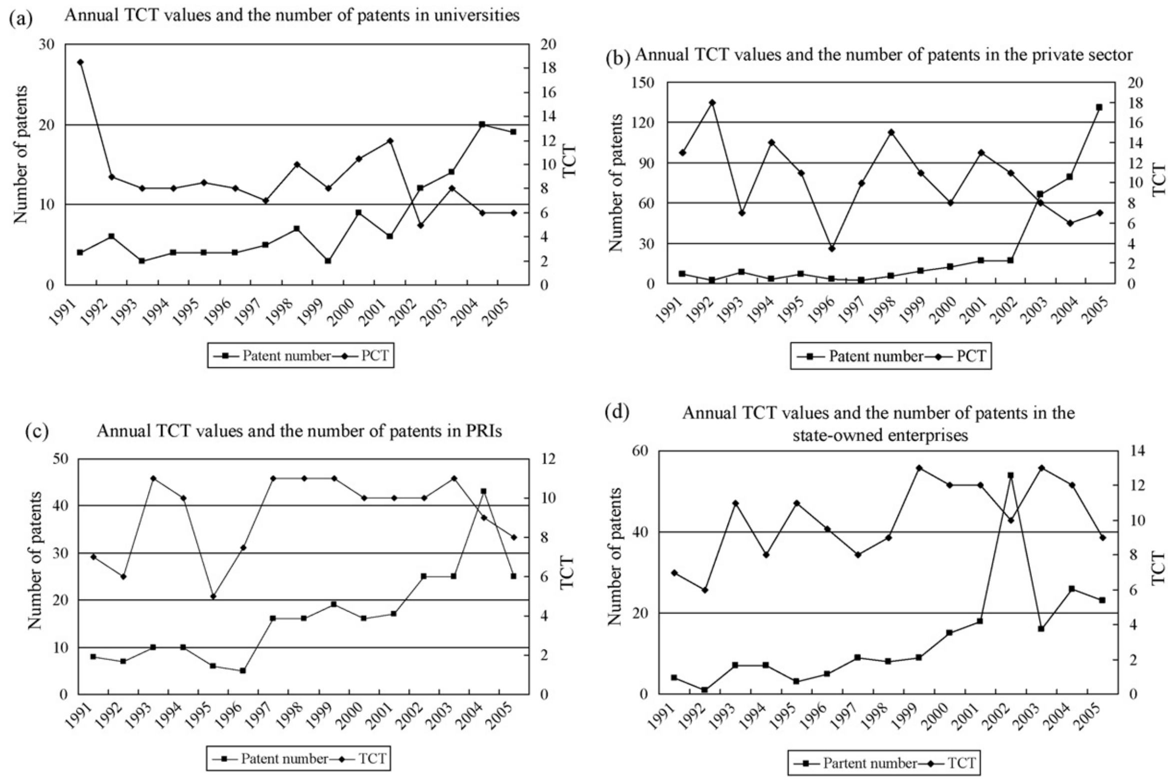

Fig. 8. (a) *Source*: USPTO search and calculated by the authors. (b) *Source*: USPTO search and calculated by the authors. (c) *Source*: USPTO search and calculated by the authors. (d) *Source*: USPTO search and calculated by the authors.

in science and the relationships between technology cycle time and science linkage. As shown in Fig. 9, we find that foreign-owned ventures have enjoyed the lowest cycle times but not the highest level of science linkage, while the private sector demonstrates falling cycle terms and the highest degree of science linkage. We interpret this to mean that foreign companies are not yet transferring the most advanced science-based technologies to China. The PRIs exhibit a rising cycle time and relatively low linkage with science, while the universities exhibit falling cycle times and a relatively higher link with science. The lowest science linkage and rising cycle times are found in the SOEs – which is as good an indication as any of the need to reform and restructure the State-owned sector in China.

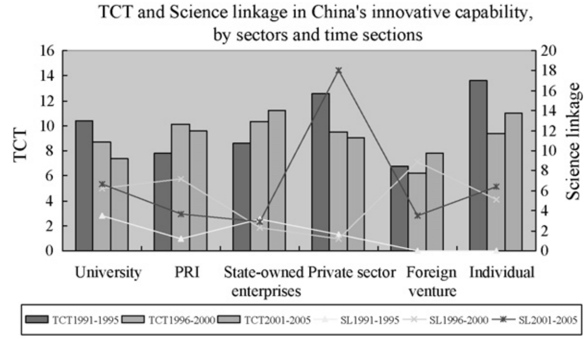

Fig. 9. *Source*: USPTO search and calculated by the authors.

5.7. *Industrial focus: strong focus on chemical industry*

We showed in Table 1 above that the top patentee from the PRIs in China has consistently been the Research Institute of Petroleum Processing, as well as the Fushun Research Institute of Petroleum and Petrochemicals, the Shanghai Institute for Biochemistry (a division of the Chinese Academy of Sciences), the Dalian Institute of Chemical Physics, the Changchun Institute of Applied Chemistry, and the Beijing Research Institute of Chemical Industry. This overwhelming bias in patenting activity by PRIs towards the chemical and petrochemical sector reflects the production and strategic needs of the country, and it also reveals why specialization in the electronics industry was found to exert a negative influence on national innovative capacity – for the simple reason that no top PRI involved in electronics has been patenting to date. We expect this situation to rapidly change as the restructuring of PRIs begins to take effect in future years.

Fig. 10 reinforces this point from the perspective of patenting rates at the USPTO by the Chinese public sector in general (not just PRIs) analyzed by technological specialization, which again demonstrates a focus on chemical and petrochemical technologies, in which the sectors C07 (organic chemistry) and C08 (organic macromolecular compounds) dominate. This again is consistent with China pursuing a highly targeted latecomer strategy, where a focus on chemicals and petrochemicals is revealed to be of

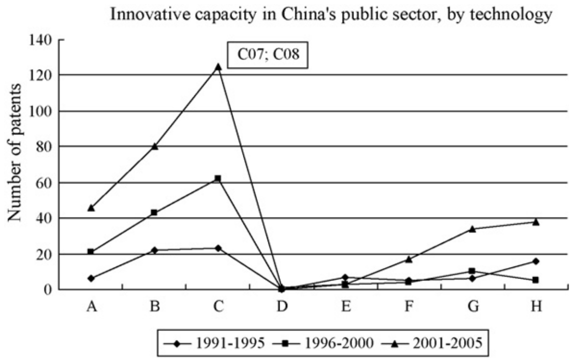

Fig. 10. *Source*: USPTO search and compiled by the authors.

profound strategic significance via the evidence of patenting activities.

6. Discussion

Previous studies of innovative capacity in OECD countries have found that national innovative capacity (NIC) is grounded broadly in a number of variables associated with each nation's common innovation infrastructure, the environment for innovation in the nation's industrial clusters, and the linkages between these two (as for example in terms of university R&D expenditure, and strength of venture capital). By contrast, in the latecomer 'East Asian Tiger' economies, Hu and Mathews (2005) found instead a concentration on just four variables having a significant impact on patenting rates, namely patent stocks, R&D manpower, private R&D expenditure, and specialization in high tech industry (combined with public R&D funding). Other variables such as openness, university R&D, investment in education, and availability of venture capital, did not have any significant impact on patenting rates in these countries in their latecomer, catch-up stage (measured up to the year 2000). This is consistent with the necessity for latecomer countries in catch-up mode to target their efforts and concentrate their meagre resources on just a few sectors. So it makes sense that in the East Asian Tiger Economies (mainly Korea and Taiwan) patenting rates would be influenced by just these four factors – and in particular by public R&D conducted in PRIs like ITRI in Taiwan or KIET in Korea which played an important role in bringing the firms in these countries abreast of international technological developments.

6.1. The role of universities

Now in repeating this exercise for China, and updating the analysis to the year 2005, we find some continuity in these themes but also some striking differences. The first variation is the important role played by universities in contributing to innovative capacity. When GDP per capita is taken as proxy for the knowledge stock, then we find that university R&D expenditure is found to have a significant positive impact on GDP as a driver of patenting – unlike the case for the East Asian Tigers where university R&D had a small but not significant impact. Is this plausible? Actually, the universities in the East Asian Tigers played a prominent role in their development but largely as builders of a skilled manpower base, particularly in generating engineering talent for high-tech industries. This pattern has been followed in China as well, except that in China the universities, quite unlike the experience of the Tigers, have not only been a critical source of innovative activity but also been a practitioner by means of forward engineering and spin-offs. As noted above, the impact of China's university reforms has been marked, particularly during the significant growth period of China's GDP: no fewer than 42,945 firms were spun off from universities during the 7-year period from 1997 to 2004 – a number unprecedented in the earlier experiences of developing countries. This can be taken to mean that university R&D has contributed to innovation capacity partly by these spinoffs' contribution to GDP and partly in the role that universities played in training skilled manpower (as in the wider East Asian case). Our finding is consistent with the few studies that exist of China's universities and their contribution to the country's industrial development – such as Lee (2005), Chen and Kenney (2007), and Xue (2005) amongst others. Nevertheless, there is clearly much here that calls for further research.

6.2. The role of public research institutes

The second striking difference, which becomes evident when patent stock is used as proxy for knowledge stock, is the positive moderating role played by private R&D expenditure, and the negative moderating role played by public R&D. This is quite paradoxical, and seems at odds with the results for the East Asian Tigers, where public R&D was found to play an important and positive role in building innovative capacity (Mathews and Hu, 2007).

However, the contribution of China's public R&D may need to be counted in different ways. In fact, China's PRIs, at both the local and national levels, were the backbone of the nation's innovation system before the mid-1990s, when more than half the country's government-funded R&D expenditure was allocated to the PRIs (National Bureau of Statistics, 2005). Since the institutional reforms were started in the 1990s, many PRIs transformed themselves into private technology service enterprises or were affiliated with corporate groups as the means for their survival. Through these technology service and licensing activities, the PRIs were able to emerge as a critical driver of (but not as a direct contributor to) China's national innovative capacity. The critical but implicit role of the public research institutes (PRIs) in China's industrial development was evident in the very different experiences of China's telecommunications and textile industries. Let us therefore look briefly at some cases from these industries.

6.2.1. Telecommunications

China's two most innovative telecommunications equipment companies, Huawei and ZTE (Zhongxing Telecom Equipment Corporation) with their outstanding performance in the global market, are found to have intensive relationships with China's PRIs. Huawei Technologies was established in 1988 and now has become one of the leading vendors of switching systems in the global telecommunications market. In 2007, Huawei rose to become the fourth largest patent applicant in the world under the WIPO Patent Cooperation Treaty (PCT); in the same year it was recognized by Forbes magazine as one of the 200 World's Most Respected Companies. Apart from leveraging external technology through its six overseas R&D centers, Huawei operates another six domestic R&D centers in Beijing, Shanghai, Nanjing, Hangzhou, Xi'an, and Chendu. All these domestic R&D centers work closely with restructured PRIs such as the Research Institute of Telecommunications Transmission, the China Academy of Telecommunication Research, Xi'an Electronic Engineering Institute, and Beijing Design Institute, thus providing a glace of the importance of these PRIs for Huawei's own technological development. Similarly, the second largest telecommunications company, ZTE, established in 1985, now has a total of 14 R&D centres worldwide, 8 of which are located in China. These latter work closely with about 50 local research institutions in pursuit of a variety of R&D collaborative projects.

6.2.2. Textiles

By contrast, China's textile industry provides an extermely different experience from that in telecommunications industry. China's textile industry is one of the so-called 'traditional industries' with a lower technological capability and operating under very intensive domestic competition. Some of the technologically most sophisticated of China's PRIs are found in the textile highly related chemical and material areas – as demonstrated in Fig. 10. The study by Liu et al. (2006) reveals that the patenting activity in China's textile industry is critical for the growth of a company like Grace Corporation, which has enabled the company to leapfrog from a small state-owned enterprise established in 1984 into one of the world's largest rayon manufacturers by the year 2005. The key to the successful technological upgrading in Grace Corporation lay in its reliance on the building of internal technological capability rather than on technological diffusion from the related PRIs. In addition, while many domestic cross-licensing agreements have been struck, driven by patent infringement suits in China's textile industry, the PRIs are still found to play little role in its success.

It is clear that the transition of China's PRIs is an ongoing process. The contribution of PRIs to the development of China's national innovative capacity over the past 15 years is only revealed when the output of the restructured PRIs is incorporated with the private R&D sector. In other words, the impact of the PRIs on national innovative capacity is effected indirectly through private R&D rather than through public R&D directly. Support for this interpretation of the anomalous role played public R&D in China is also found in the inefficiency and ill-disciplined character of the PRIs, which have only been streamlined and slimmed down since the late 1990s and early 2000s. Prior to the year 2000, China's PRIs, even before the recent reforms, have played a small but not significant role in enhancing innovative capacity, but this has now been swamped out by incorporating their effect with that of private R&D, especially since the private sector started taking a keen interest in patenting after China's entry into the WTO in 2001. Note that nearly 70% of China's R&D manpower had traditionally been found in the public sector – meaning, in universities, in PRIs or in SOEs. Much of this manpower was devoted to military and energy pursuits, where patenting activity was mostly conducted by and within certain public institutes (e.g. China Petro-Chemical Co. (the SOE) and Research Institute of Petroleum Processing (the PRI)) when the contribution to the diffusion of innovation generally was not seen as a priority. These all demonstrate that the innovation performance (in terms of patenting rate) of China's PRIs is mostly concentrated in certain institutes rather than across the board.[11]

6.3. Examining the quality of patenting activity

Partly to investigate more deeply these two apparent anomalies, and partly to see what else of interest might show up, we took our investigation to a second stage, where we could highlight the different contributions of the various sectors to the patenting activities at the USPTO, and analyze their effectiveness. We emphasize that this second part of the exercise does not involve the full apparatus of regression analysis to identify the drivers of NIC, but a closer examination of the patenting process itself, building a quality dimension to our analysis to complement the purely quantitative dimension of the NIC analysis. The two parts of our analysis are thus complementary. We divided the patenting experience in China at the USPTO into six categories, or sectors – namely university R&D, public sector R&D (PRIs), state-owned enterprises (SOEs), private (domestic) firms and foreign owned ventures (where the venture takes the name of the foreign firm, even if it is partly domestically owned). This categorization enables us to examine what has happened to patenting rates by PRIs and by the private sector and by universities as separate agencies. We focus on seven analytical features, namely (1) patent rates overall; (2) patent growth rates; (3) patent intensity (the R&D$ cost of a patent); (4) technological impact (forward citation rate); (5) knowledge base or absorptive capacity (backward citation frequency); (6) technology cycle time; and (7) TCT and science linkage, which is a direct measure of technological progress.

Our most striking findings from these analyses are the rapid rise of patenting by the private sector after 2000, and the evidence for the greater efficiency and impact of this patenting activity – whether measured by falling cost of each patent, or rising impact via forward citation, or diminishing cycle time (faster turnover) as patent rates increase after the year 2000, and the rising level of linkage with the science base (i.e. rising level of citations by patents to the science literature).

Even though PRIs were dominating with the highest patenting rate in China up to the year 2000 (albeit still small by international standards), their innovation performance was mostly confined to a few PRIs and concentrated in the chemicals and petrochemicals area. After the year 2000,

[11] This calls attention to the fact that the use of patent data in analyzing innovation activity needs to take cognizance of the historical and industrial background, particularly in the case of the catching-up latecomers.

the PRIs' innovation activity was overtaken and blended into that of the universities and particularly incorporated within the private sector and foreign owned enterprises. The rate of patenting by PRIs themselves fell after the year 2002 (indicating a decline in applications for patents dating from 2000) and the forward citation frequency also dipped after 2002, indicating that the PRI patents were having less impact than previously. Meanwhile the cycle time of patents taken out by the PRIs shows no discernible trend in terms of technological progress.

We see these contrasting experiences as providing a further explanation for our argument: the contribution of China's PRIs in reinforcing China's national innovative capacity can only be identified when the restructured PRIs exert an indirect effect through being incorporated with the private R&D rather than exerting a direct effect as public R&D. Unlike the case of the East Asian Tigers, China inherited a large and unwieldy public sector from the closed communist era, and it has taken a long time to dismantle it and make it efficient. Meanwhile new sources of innovation have been unleashed, with the university sector as a whole playing a role equivalent in entrepreneurial drive and efficiency to the private sector in other systems, and the private sector itself, together with the foreign-owned sector, rapidly moving to the lead in patenting after the turning point in the year 2001 when China joined the WTO.

China is still at a relatively early stage in the evolution of its national innovation capacity, and we would expect to see the streamlined public sector, after its restructuring and transition, now coming to play a role similar to the role played in the East Asian Tigers, as steering and leveraging institutions for technological capacity, once the less efficient organizations had been eliminated.

7. Concluding remarks

China has achieved a remarkable transformation over the past two and a half decades, with superlative rates of growth driven largely by high levels of investment, both domestic and foreign-sourced. Its openness to investment and trade, combined with its latecomer advantages in low costs, has made it the world's export platform for manufactured goods. But the real question for its future concerns its capacity to move from imitation to innovation, since it is through an economy's capacity to sustain innovation that its future prosperity is secured. In China's case, our study demonstrates that the foundations of national innovative capacity are already being laid. National innovative capacity depends, in China's case as in the case of the East Asian Tigers (Korea, Taiwan, Singapore), on a few key sectors, with universities playing a much more important role in China's case than in the Tigers while the contribution of the PRIs in reinforcing China's national innovative capacity is exerted indirectly through private R&D rather than through public R&D directly. It is a fact that the private sector activity has really taken off since the early years of the 21st century, and this is demonstrated clearly in our deeper analysis of China's patenting activity at the USPTO, touching on propensity to patent (costs in R&D per patent), the impact of patents in terms of frequency of subsequent citation, the extent to which patents draw on earlier bodies of knowledge (absorptive capacity), the diminishing cycle times, and the strong linkage with the science base. All this promises much for the Chinese national system of innovation.

The outstanding puzzling feature of China's innovative capacity to date is the less than stellar performance of its public sector in providing a means to steer the overall technological development of the country through its catch-up stage. We have offered an original solution to this paradox, based on our findings in this study, that the streamlining of the public research sector from the late 1990s, and having an effect from the early 2000s, will enable the PRIs to play the steering role that one would expect them to play in a latecomer country based on the earlier experience of the East Asian Tigers.

Acknowledgements

The first author would like to acknowledge the financial support of the National Science Council (96-2416-H-005-027-MY3). Valuable comments from two anonymous reviewers are also acknowledged.

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