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INDIGENOUS INNOVATION IN CHINA: IMPLICATIONS FOR SUSTAINABLE GROWTH

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IMPLICATIONS FOR SUSTAINABLE GROWTH

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Abstract: This paper aims to examine indigenous innovation and draw implications for sustainable economic growth in China. It investigates China's capacity and achievements in indigenous innovation at both the macro and micro levels. China's indigenous innovation is also compared to that in other major economies in the world. It is found that China's innovation development is well ahead of other economies at the similar stage of development but there is a gap between China and the world's leading innovative economies. Both aggregate and disaggregate evidence shows that China is catching up rapidly with the world's innovation leaders. If current growth momentum is maintained, China is well positioned to become one of the most innovative economies in the world in the coming decade. There are however some serious issues to be resolved before China's innovation potential could be realized.

Key words: Indigenous innovation, R&D, Chinese economy

JEL codes: O32, O33, O38

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Introduction

After three decades of rapid growth, the Chinese economy is now at the crossroads heading to the next phase of development. While China's economic growth has indeed been phenomenal it has also been resource-intensive and environmentally-damaging. To sustain high growth in the coming decades, the role of technological progress has to be boosted. Technological progress within a country can be due to technology transfer from abroad or indigenous innovation. The former has been widely discussed in the literature on the Chinese economy. For example, Wei and Liu (2006) examine productivity spillovers from exporting and foreign direct investment (FDI) in the Chinese manufacturing sector, Tian (2007) and Liu et al. (2009) investigate technology spillovers from FDI and multinational corporations (MNCs), and Kuo and Yang (2008) analyse knowledge spillovers and regional economic growth. The innovation capacity and achievements of indigenous firms in China are, however, under-documented.[1] The objective of this chapter is to examine China's indigenous innovation capacity and to explore the potential for innovation to provide a key source for sustainable growth in the future. The chapter begins with a review of China's innovation capacity and achievements. This is followed by an analysis of innovation at the firm level. Subsequently, China's innovation is examined from an international perspective, before discussing the implications for sustainable growth in the country.

China's Innovation Capacity and Achievements

China has adopted an active science and technology development program since the foundation of the People's Republic in 1949. Moreover, the program has for a long time been biased towards technological advancement in defence-related sectors. Science and technology as an important source of economic growth more generally has only been recognised and promoted recently. This is clearly envisaged in the country's "National Medium- and Long-term Program

[1] General surveys about China's research and development (R&D) sectors are available in Gao and Jefferson (2007), OECD (2009) and Zhang et al. (2009).Wei and Liu (2006) and Jin et al (2008) also covered R&D marginally.

for Science and Technology Development (2006-2020)" released in early 2006 (hereafter the "2020 Program").[2] The aim of the "2020 Program" is to make China an innovation-oriented society by the year 2020 and one of the world's leading innovators in the longer term.

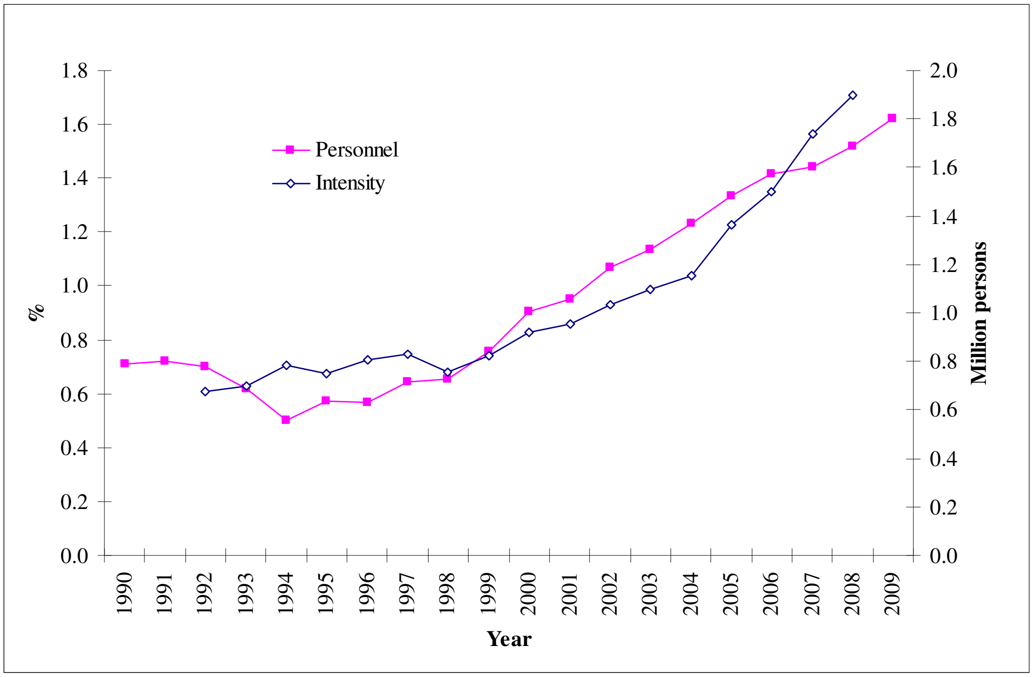
The key goals and priorities in China's science and technology development in the coming decade are detailed in the "2020 Program" document. According to this document, China will

- Give priority to technological development in 11 major sectors such as energy, water resources and environmental protection in the coming 15 years.
- Further improve the national intellectual property rights (IPR) system and strengthen the enforcement of IPR protection laws and regulations.
- Encourage enterprises to play the key role in innovation through their involvement in state projects and the provision of tax incentives and other financial support.
- Boost investment in science and technology. By 2020, China's research and development (R&D) expenditures will account for about 2.5 percent of the country's GDP.
- By 2020, derive 60 percent or more of its economic growth from technological progress. The number of patents granted to and total citations of journal articles by Chinese nationals are expected to be ranked among the top five in the world.

To provide an assessment of China's indigenous innovation capacity, several indicators can be considered. The most important factor underlying indigenous innovation is R&D spending. Associated with the implementation of the "2020 Program", there has been a dramatic increase in R&D expenditure in recent years. For example, during 2005-2009, R&D expenditure grew at an average real rate of 19.4 percent, twice as fast as the growth of China's GDP.[3] As a result, R&D expenditure as a proportion of GDP (or R&D intensity) in China has risen from 0.71% in 1990 to 1.62 percent in 2009 as shown in Figure 1. The same figure also illustrates that China's

[2] The "2020 Program" was released by the State Council, People's Republic of China on February 9, 2006 (www.gov.cn).
[3] The average growth rate of R&D expenditure is calculated using data from NBSC (2009, 2010) and YST (2009).

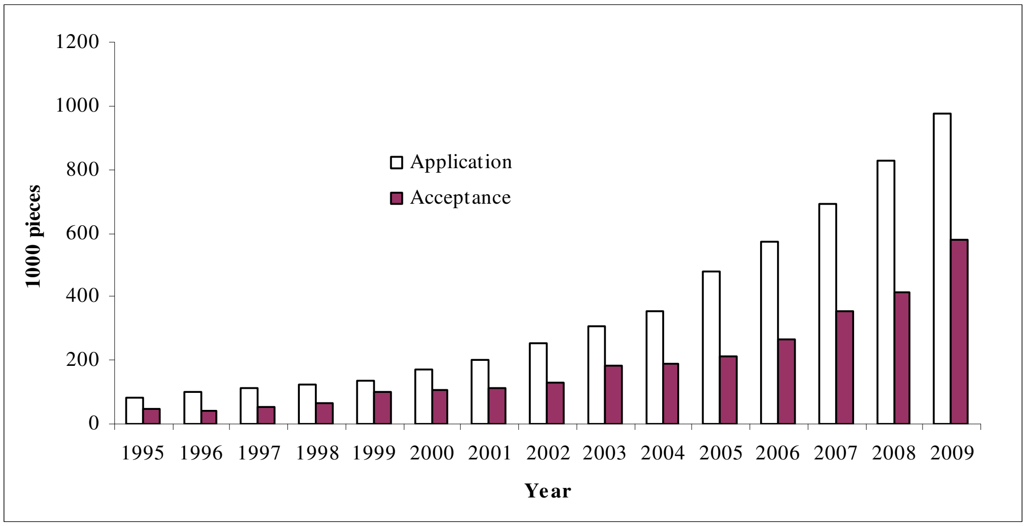
R&D personnel increased from about 670,000 (full-time equivalent) persons in 1992 to 1.9 million in 2008. This growth was particularly rapid in recent years with an average rate of 13.4 percent during 2005-2008. In addition, the number of fresh graduates in sciences, engineering and medicine increased from 476,110 in 1995 to 2.7 million in 2008 (NBSC, 2009).



Sources: NBSC (2009, 2010) and YST (2009).

Figure 1 China's R&D Intensity and Personnel, 1990-2009

With the expansion of R&D inputs, China's innovation capability and outcomes have increased too. For example, the numbers of domestic patent applications and registrations grew from 69,535 and 41,881 items in 1995 to 878,000 and 502,000 items in 2009, respectively (Figure 2). During the same period, the number of Chinese applications for patent registration offshore also increased from 13,510 to about 99,000 items, with the number of registered patents rising from 3,183 to 80,000 (NBSC 2009, MST 2010). In addition, it is reported that the number of publications by Chinese scientists and engineers increased from 65,000 to 208,000 between 1995 and 2007.[4]



Sources: NBSC (2009, 2010) and MST (2010).

Figure 2 Numbers of Patents Applied and Accepted, 1995-2009

There are, however, considerable variations among the Chinese regions. Among the 31 administrative regions in China, R&D intensity varied from less than 0.5 percent in six regions to more than 2.0 percent in four regions in 2008 (Table 1). In terms of human resources, the number of R&D scientists and engineers per million population ranged from 161 in Tibet to 9,833 in Beijing. Table 1 also shows that the number of patent registrations per million population lies between 32 in Tibet and 1,296 in Shanghai in 2008. In general, large disparities exist between the coastal regions and the rest of the country (i.e., the central and western regions). Furthermore, if the number of patent registrations per 1,000 scientists and engineers is defined as an indicator of R&D performance then, in general, provincial-level performance and inputs are positively related, as expected and as depicted in Figure 3. However, the Figure also highlights

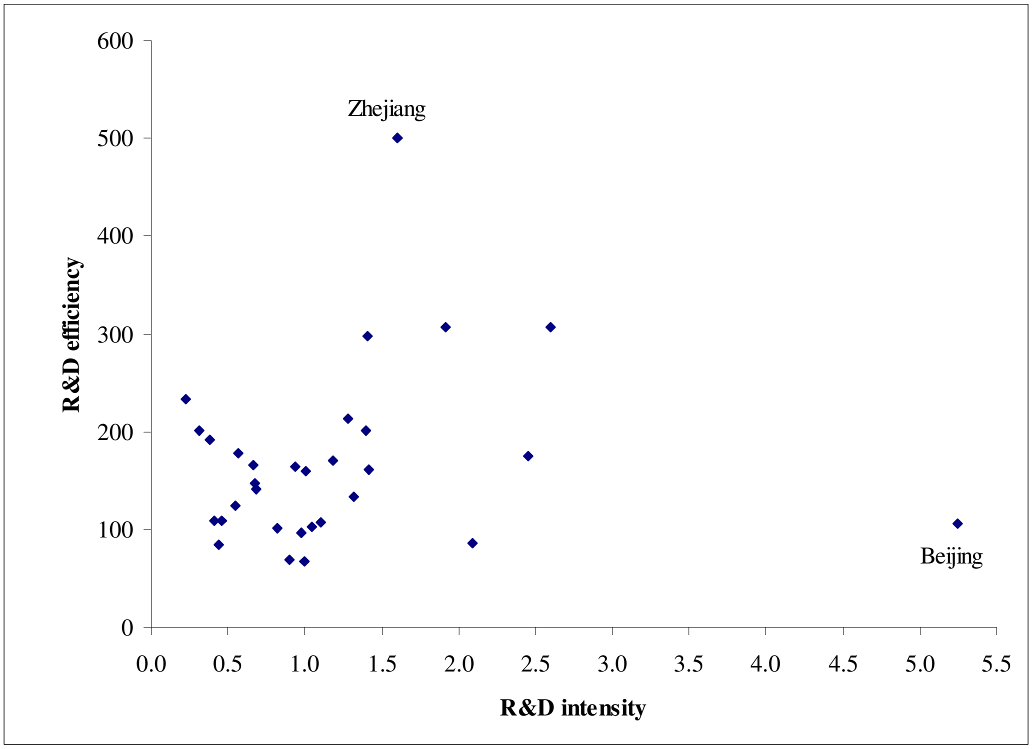
[4] Those numbers are based on the science citation index (SCI), engineering index (EI) and index to scientific and technical proceedings (ISTP) databases according to YST (2009).

two clear outliers, with Beijing underperforming and Zhejiang achieving an excellent performance in 2008 at least.

Table 1 China's Regional R&D Statistics in 2008

Regions	Expenditure over GRP (%)	Scientists and engineers per million population	Number of patents per million population
Coastal mean	*1.96*	*2830*	*601*
Beijing	5.25	9833	1047
Shanghai	2.59	4212	1296
Tianjin	2.45	3293	577
Jiangsu	1.92	1887	579
Zhejiang	1.60	2067	1034
Liaoning	1.41	1538	247
Guangdong	1.41	2186	650
Shandong	1.40	1408	283
Fujian	0.94	1345	220
Hebei	0.67	535	79
Middle mean	*0.85*	*731*	*84*
Hubei	1.31	1103	147
Anhui	1.11	655	71
Heilongjiang	1.04	1168	120
Hunan	1.01	604	96
Jiangxi	0.97	540	52
Shanxi	0.90	974	67
Jilin	0.82	1085	109
Henan	0.66	583	97
Guangxi	0.46	426	46
Hainan	0.23	172	40
Western mean	*0.81*	*597*	*80*
Shaanxi	2.09	1352	117
Sichuan	1.28	768	164
Chongqing	1.18	995	170
Gansu	1.00	593	40
Ningxia	0.69	694	98
Guizhou	0.57	257	46
Yunnan	0.54	357	44
Inner Mongolia	0.44	647	55
Qinghai	0.41	377	41
Xinjiang	0.38	366	70
Tibet	0.31	161	32

Sources: NBSC (2009) and STY (2009)



Sources: R&D intensity and efficiency values are calculated using data from NSBC (2009) and YST (2009). R&D efficiency is defined as the number of patent registrations per million scientists and engineering.

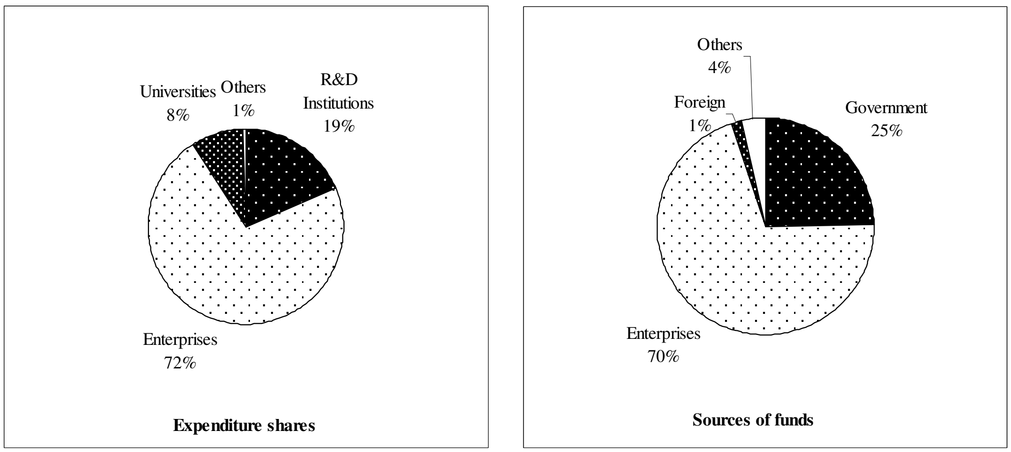
Figure 3 China's R&D Intensity and Performance in 2008

Innovation at the Firm Level

Chinese enterprises have played an important role in promoting growth of the country's innovation capacity. Since the mid 1990s, Chinese enterprises have become the leading players in R&D investment and execution (NBSC, 2009). By 2008 they had become the dominant force accounting for more than 70 percent of the country's R&D investment and spending (Figure 4). This growth is also reflected in the changing share of patents registered by the enterprise sector over the national total. This share increased from 12 percent in 1995 to 34 percent in 2008.[5] However, the expanded role of Chinese enterprises might have led to more market-driven R&D investment. This is reflected in the movement of two indicators. First, the share of basic and

[5] Those share figures are calculated using China's patent data (NBSC, 2009).

applied research expenditure over total R&D spending declined from 32 percent in 1995 to 17 percent in 2008 (NBSC 2009). Second, the share of "invention" patents over total domestic patents registered peaked at 25.9 percent in 2004 and has since fallen, reaching 22.7 percent in 2008 (NBSC 2009).[6] The challenge ahead for policy makers is to ensure that market-oriented R&D activities do not grow at the expense of long-term innovation capacity building in the country.



Source: NBSC (2009).

Figure 4 China's R&D Expenditure Shares and Sources of Funds, 2008

In terms of innovation activities and efforts, heterogeneity exists across sectors as well as among firms. The first national survey of firm innovation activities was conducted by the National Bureau of Statistics of China (NBSC) in 2007. Detailed information about firm-level innovation activities was collected over a three-year period (2004-2006). The survey covered all large and medium firms and a sample of small firms.[7] Among the 299,995 firms surveyed, there were 2,674 large firms (0.9 percent), 29,622 medium firms (9.9 percent) and 267,699 small firms (89.2 percent). Only 86,342 firms, less than one third of the total, were actually engaged in

[6] Chinese patents are generally grouped into three categories, that is, inventions, utility models and designs.
[7] According to the official Enterprise Classification Standards adopted in 2003, Chinese firms are grouped using three criteria, namely, the number of employees, sale revenue and value of assets. For example, the number of employees is above 2000 for the large firms, between 300 and 2000 for the medium firms and below 300 for the small firms in the manufacturing sector (www.stats.gov.cn).

innovation activities (NBSC, 2008). According to the survey, large firms were found to have the highest rate (83.5 percent) of participation in R&D activities followed by small (25.2 percent) and medium (55.9 percent) firms. At the industry level, the top five sectors in terms of participation rates were pharmaceuticals (63.7 percent), instruments and office machines (60.7 percent), tobacco (55.2 percent), communication and other electronic equipment (46.8 percent) and special measuring instruments (46.5 percent).[8] All of these sectors other than tobacco belong to the so-called high-technology (hereafter hi-tech) sector.[9]

On average, innovative firms in 2006 spent about 1.9 percent of their business income on innovation. Though this figure is larger than China's R&D intensity, there is huge disparity between firms. Large firms on average invested about 2.7 percent of their business income in R&D which is well ahead of the medium (1.8 percent) and small firms (1.0 percent) (NBSC, 2008). The large and medium enterprises (LMEs) as a group accounted for 81.1 percent of total expenditure on innovation in 2006. They also had a value share of 78.7 percent in the output of new products which may be used as an alternative indicator of innovation outcome. For this reason, most studies of innovation at the firm level in China focus on LMEs (such as Jefferson et al. 2003, Girma et al. 2009).

The analysis below provides a study of R&D determinants, strategies and intensity in Chinese firms using panel data of 19,880 LMEs over the period of 2005-2007.[10] Three different yet related models are estimated. These models in turn deal with three issues, namely, the determinants of innovation, the choice of R&D strategies and the intensity of R&D spending in Chinese firms. The baseline model can be presented as follows:

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[8] The percentage figures in parentheses are the rates of participation in R&D activities according to NBSC (2008).
[9] The National Bureau of Statistics of China (NBSC) released a circular to introduce the Catalogue for High-technology Industrial Statistics Classification in July 2002 (www.stats.org.cn).
[10] See Wu (2010) for a more detailed presentation and discussion.

$$Y_{it}^{*} = \alpha_0 + \Sigma\beta_j X_{ij(t-1)} + \Sigma\gamma_j Z_{ijt} + \varepsilon_{it} \quad (1)$$

where Y^{*} is a latent variable which has a value of unity or zero for the first two models (namely the determinants of innovation and choice of R&D strategies models) and measures firm-level R&D intensity in the third model (namely the intensity of R&D spending model). The lagged variables (*X*) capture the effects of the age and size of each firm, its level of liability or debt burden, level of production technology, intangible assets and long-term investment. The *X*-variables are lagged one period to avoid potential simultaneity problems in the models. Specifically, these variables (*X*) are defined as follows:

- *AGE* is simply the age of the firm (years in existence);
- *SIZE* reflects the size of the firm, measured using the number of employees;[11]
- *DEBT* measures the degree of liability, defined as the ratio of total liability over the total value of assets;
- *TECH* captures the level of technology in production, measured by the ratio of the net value of assets over employment (i.e., the capital-labour ratio);
- *INTANG* reflects whether a firm has intangible assets (such as patents). It is defined as one if the firm has intangible assets and zero otherwise; and
- *INVEST* takes the value of one if a firm has long-term investment and zero otherwise.

Other independent variables, namely the *Z* variables in equation (1), are introduced to reflect firms' productivity performance and exporting status, industry concentration and variations across firms with regard to ownership, location, industry and time. These variables (*Z*) include:

- *EFF,* which is an indicator of firm efficiency and measured simply by the firms' labour productivity, that is the ratio of output value over total employment;

[11] There are of course other measures of firm size such as total output value, the value of total sales and so on. The number of employees is chosen so that few observations are dropped due to missing data.

- *EXP,* which is a binary variable and has a value of one if a firm is engaged in exporting and zero otherwise;
- The Herfindahl index (*HERFINDAHL*), which is computed to measure the level of competition or concentration of business activities in a sector. The calculation is based on the four-digit classification of Chinese industrial sectors;
- Four ownership dummy variables, which are included to represent firms owned or controlled through majority share holding by the state, investors from Hong Kong, Macau and Taiwan (*HMT*), foreign investors and shareholders (versus all other firms).
- Five dummy variables, which capture variations among firms located in the areas of Beijing, Shanghai, Pearl River delta, the six "middle" provinces, the three north-eastern provinces and western China with the north-eastern provinces being chosen as the reference region.[12]
- Eleven sector dummy variables to reflect potential sectoral differences among the firms, which are categorized into 12 industry sectors on the basis of the official Standard Industry Classification (SIC) grouping.

The estimation results of the three models are presented in Table 2. According to the results of Model 1, it is found that large or old firms are more likely to invest in innovation. Exporters and capital-intensive firms are also shown to have higher probabilities of spending on R&D. So are firms with long-term investments, intangible assets, and better performance (in terms of labour productivity). It is also found that the probability of innovation tends to increase over time and that more competition increases initially and then reduces the probability of innovation. This is consistent with evidence from other economies (Aghion et al. 2005, Tingvall and Poldahl 2006). Firms which are less likely to invest in R&D are often burdened with heavy debt or owned by

[12] Specifically, China's 31 administrative regions are partitioned into six groups and represented by six dummy variables, namely REG1 (Beijing, Tianjin, Hebei and Shandong), REG2 (Shanghai, Jiangsu and Zhejiang), REG3 (Guangdong, Fujian, Guangxi and Hainan), REG4 (Shanxi, Anhui, Jiangxi, Hubei, Hunan and Henan), REG5 (Liaoning, Jilin and Heilongjiang) and REG6 (Inner Mongolia, Ningxia, Tibet, Xinjiang, Gansu, Guizhou, Qinghai, Shaanxi, Sichuan, Yunnan and Chongqing).

offshore investors, in particular investors from Hong Kong, Macau and Taiwan. The latter have a large presence in the Pearl River Delta region. This finding implies that, while many foreign firms may have moved to China in order to take advantage of the cheap labour there, the country's foreign investment policies might not be succeeding in providing incentives for foreign firms to invest in R&D in China.

Table 2 Econometric Estimation Results

	Model 1		Model 2		Model 3	
Variables	Coefficients	*p-values*	Coefficients	*p-values*	Coefficients	*p-values*
Intercept	-2.2088	*0.000*	-1.3537	*0.000*	0.1013	*0.025*
AGE	0.0098	*0.000*	0.0087	*0.000*	0.0024	*0.000*
AGE^2					-0.00005	*0.000*
SIZE	0.0000	*0.051*	0.0000	*0.000*	0.0000	*0.543*
EXP	0.3319	*0.000*	0.2535	*0.000*	0.0321	*0.000*
DEBT	-0.1763	*0.000*	-0.2149	*0.001*	-0.6026	*0.000*
TECH	0.0001	*0.000*	0.0000	*0.009*	0.0000	*0.832*
EFF	0.0000	*0.011*	0.0000	*0.771*	-0.0001	*0.000*
INTANG	0.2223	*0.000*	0.1789	*0.000*	-0.0358	*0.000*
INVEST	0.4580	*0.000*	0.3566	*0.000*	0.2252	*0.000*
HERFINDAHL	3.0130	*0.000*	2.6715	*0.000*	3.8713	*0.000*
$HERFINDAHL^2$	-9.6779	*0.000*	-8.3931	*0.004*		
Region dummies	yes		yes		yes	
Ownership dummies	yes		yes		yes	
Year dummies	yes		no		yes	
Seudo -R^2	0.1480		0.0842		0.6091	
Sample size	59640		27102		13446	

Notes: Models 1 and 2 are estimated using quadratic hill climbing optimization algorithm and quasi-maximum likelihood (Huber-White) robust standard errors and covariance. Model 3 is estimated using panel EGLS with cross section weights and White cross-section standard errors & covariance provided in Eview 6.

The estimated coefficients (not reported in the table) of the dummy variables also show that firms engaged in manufacturing pharmaceuticals, machinery, transport equipment, communication and other electronic equipment are more likely to invest in innovation. These products are mainly in the hi-tech sectors. In fact, at the aggregate level, on average R&D intensity in the hi-tech sectors is much higher than the national average of 1.44 percent in 2007 (see Figure 1). For example, the percentage share of R&D expenditure over sectoral value-added in 2007 is 4.66 in pharmaceuticals, 15.39 in aircraft and spacecraft, 6.78 in electronic and telecommunication equipments, 3.87 in computers and office equipments, and 6.28 in medical equipments and meters manufacturing (YHT 2008). The estimation results also imply that state-owned and share-holding firms are more likely to be innovators.[13] It is also interesting to note that firms located in the central and western regions, in particular the western region, are more likely to spend on R&D. This may reflect the fact that SOEs play a more important role in the economies of the central and western regions, accounting for 25.1 percent and 30.0 percent of firms in the two regions respectively, compared with a share of 15.6 percent in the coastal area. These findings about the role of SOEs in innovation suggest that privatisation may not always be conducive to innovation (at least before China's private firms can play a more prominent role in innovation).

According to the estimation results of Model 2 in Table 2, persistent innovators -defined as firms which invested in R&D every year during the period surveyed - are more likely to be associated with large-scale production, old vintage in terms of commencement date, exporting status and high capital-labour ratios (or capital-intensive technology). Persistent innovators are also likely to have long-term investments or intangible assets. A great level of liability is found to be negatively linked with the probability of being a persistent innovator (Table 2). However, relatively efficient firms are not necessarily more likely to be persistent innovators. It is also found that firms controlled by investors from Hong Kong, Macau and Taiwan or located in the Pearl River delta region are less likely to be persistent innovators. In general, SOEs and shareholding firms are more likely to be persistent innovators. So are firms located in western China or involved in manufacturing pharmaceuticals, machineries, transport equipment, communication and other electronic equipment. These products once again are mainly produced in the hi-tech sectors, as expected.

[13] The detailed results are reported in Wu (2010).

It is found that firms' R&D intensity is negatively related to firm age (Wu 2010). However, further analysis demonstrates that firms' R&D intensity increases initially and then falls as their vintage of capital ages (Model 3, Table 2). The estimated turning point is about 25 years. Since the average age of the firms in the sample is 17, thus most Chinese enterprises are still on the upward (left) side of the invested U-shape. As for the relationship between competition and R&D intensity, there appears no evidence of an inverted U-shaped relation as argued by Aghion et al. (2005) and Tingvall and Poldahl (2006). Instead it is shown in Table 2 that R&D intensity and competition are negatively related. This supports the argument that dominant firms tend to be more innovative than non-dominant ones (Blundell et al. 1995).

It is further shown in Table 2 (Model 3) that firms' R&D intensity is positively associated with the existence of long-term investments, exporting status, large size and high capital intensity, although the last two have insignificant coefficients. It is also found that firms' R&D intensity is negatively linked with firm liability, efficiency and the existence of intangible assets. If a firm possesses intangible assets, it may imply that the firm is well established in the field (with new products or patents, for instance) and only needs R&D investment to maintain the leading edge. The negative relationship between efficiency and R&D intensity is a puzzle. It may reflect the role of SOEs in innovation. Chinese SOEs are generally less efficient but they are the key players in R&D activities in China. This is consistent with the positive sign of the coefficient of the dummy variable representing SOEs. These findings imply that China is facing a dilemma. While the need for further economic reform calls for the withdrawn or privatisation of SOEs, Chinese private firms are not ready to take over the risky business of R&D investment. Thus as far as innovation is concerned, specific policies are required to help the transition from the SOEs to the private firms.

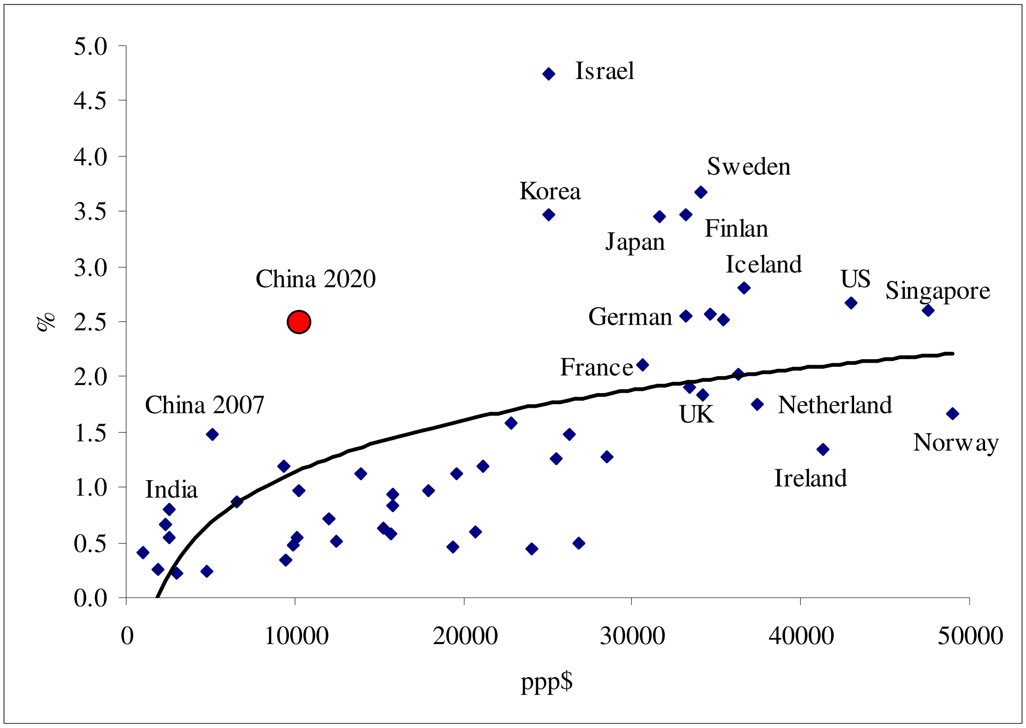
International Perspective

Among the world's major spenders in R&D, China was ranked third in 2007, only behind the United States and Japan (Table 3). However, it should be pointed out that there is still a large gap between China and the world's top two R&D investors. For example, in 2007, China's total R&D spending was about 28 percent and 70 percent of that in the United States and Japan, respectively. In terms of R&D intensity, although China is still behind the world's top R&D spenders, the country is well ahead of major economies at a similar stage of development, as clearly demonstrated in Figure 5. If current growth in R&D spending is maintained, it can be speculated that China will follow the innovation paths of South Korea and Japan and become one of the most innovative countries in the world

Table 3 World's Top Five R&D Spenders in 2007

Nations	R&D expenditure (ppp$ billion in 2000 prices)	Shares (%)			R&D personnel (million persons)
		Business	Government	Others	
US	311.4	66.2	28.3	5.5	1.426
Japan	124.6	77.7	15.7	6.7	0.938
China	87.1	70.4	24.6	5.1	1.736
Germany	58.7	68.0	27.8	4.3	0.506
France	35.6	52.0	38.2	9.8	0.372
UK	33.3	46.5	30.0	23.4	0.349

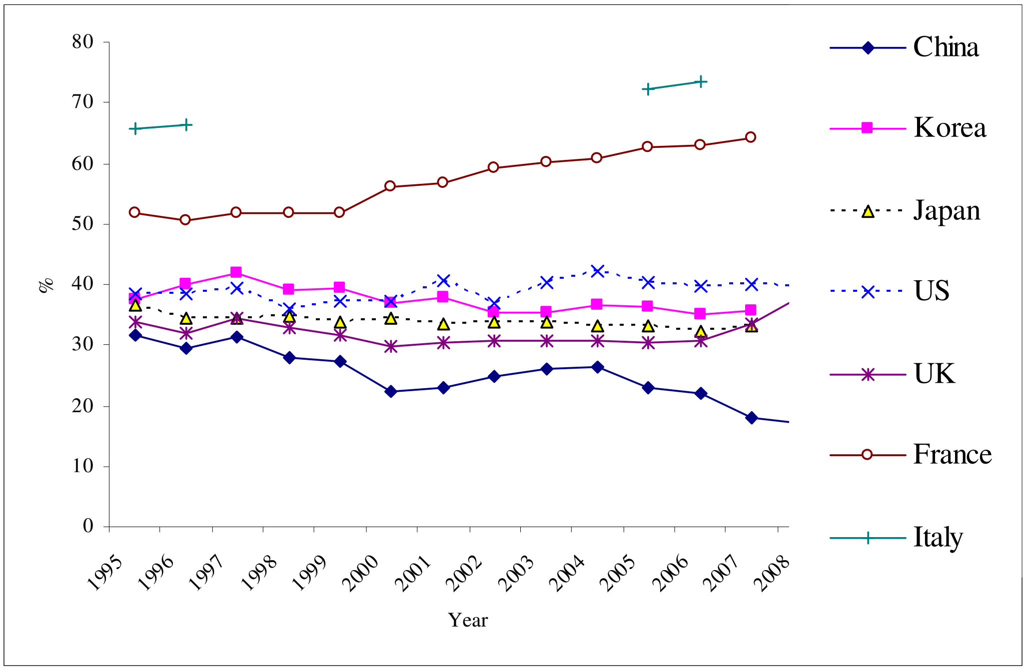
Sources: R&D expenditure and personnel data are drawn from the OECD online database (SourceOECD.org). The R&D personnel figure for the US is 2006 data.



Sources The data are drawn from the World Development Indicators online database (WDI.org) (World Bank 2010). R&D intensity is the percentage share of R&D expenditure over GDP in each country. GDP per capita is expressed in 2005 constant international prices.

Figure 5 R&D Intensity and per capita GDP in Major Economies, 2007

Furthermore, the combined share of basic and applied research expenditure over total R&D spending maintained a declining trend in recent years. It was only 17.2 percent in 2008, while this ratio is much higher and rising or relatively stable over time in the major developed economies (see Figure 6). Thus the pattern of China's R&D spending deviates from the global trend and is biased towards investment in 'development' research. As discussed above, this may have long-term implications for the country's innovation capacity-building. For instance, an emerging trend is that, among the patents granted, only 22.7 percent belongs to the "inventions" category in 2008. Thus the structure and quality of China's R&D is changing as investment increases over time.



Sources: NBSC (2009) and OECD online database(SourceOECD.org).

Figure 6 R&D Spending Shares (Basic and Applied Research) in Selected Economies

In 2006, China for the first time overtook the United States to have the world's largest R&D research team.[14] By 2008, China's R&D sector had more than 1.9 million employees of which more than 84 percent (about 1.6 million) were scientists and engineers.[15] Meanwhile, in the same year, there were about 6.1 million students including 759,385 postgraduate students who were enrolled in the schools of science, engineering and medical sciences in Chinese universities (NBSC 2009). Thus China's potential in R&D human resources is undoubtedly the largest in the world in the coming decades. The country's comparative advantage in human resources is also reflected in the R&D cost structure. Labour compensation accounted for about 25 percent of total R&D costs in 2007 which is much lower than that in many OECD countries such as Japan (39 percent), South Korea (44 percent), the United Kingdom (48 percent), the United States (57

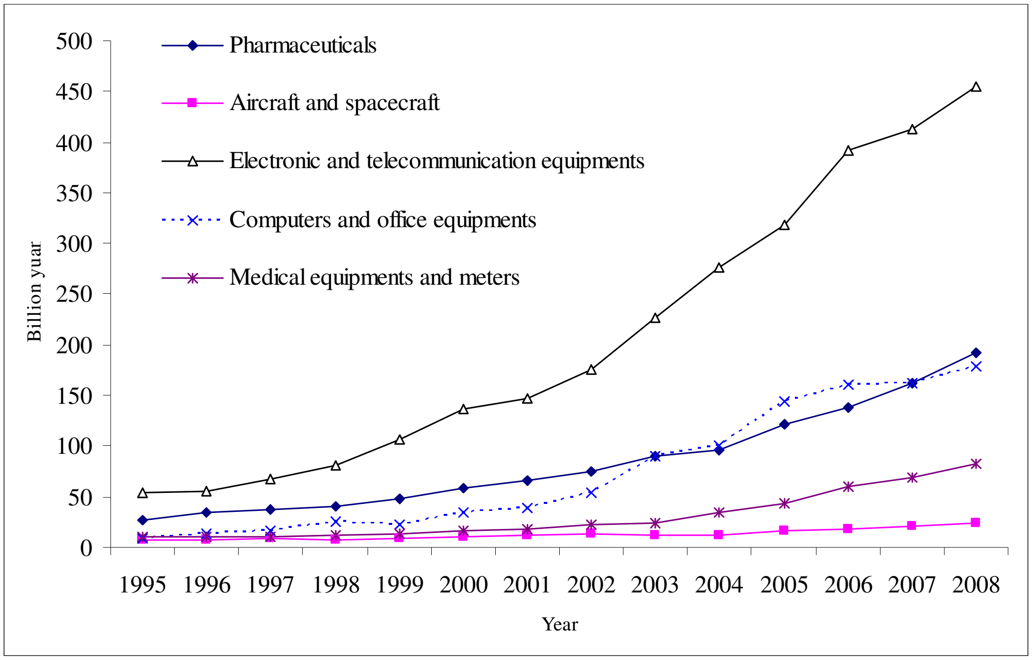
[14] This is based on data from OECD online database (SourceOECD.org).
[15] These numbers are drawn from the Annual Statistics of Science and Technology, National Bureau of Statistics of China (www.stats.gov.cn).

percent), France (57 percent) and Germany (60 percent) in the same year.[16] Therefore, China still enjoys a considerable comparative advantage in labour costs. There are, however, risks associated with low compensations paid to scientists and engineers. Skilled labour is very mobile in today's world and low wages could make China less competitive in the international talent market.

Another important factor closely related to innovation is the development of the hi-tech sector. During 1996-2007, the average real growth rate of value-added in this sector was 18.7 percent, which was twice as fast as the growth rate of the Chinese economy. This growth was led by computer and office equipment manufacturing with a real rate of growth of 28.8 percent, followed by the electronic and telecommunication equipment sector with 18.8 percent, and medical equipments and meters manufacturing with 18.0 percent (Figure 7). In 2008, the hi-tech industry as a group amounted to 12.9 percent of total manufacturing output in China (DPD, 2009). The value of exports in this sector has achieved an average rate of growth of 44.9 percent during 2002-2008.[17] In comparison with major hi-tech exporters in the world, China has the largest global market share (Table 4). In 2007 China's hi-tech sector also accounted for 29.7 percent of total manufacturing exports in the country. This figure is compatible with that in the United States which is the world's second largest exporter but is well behind those in other East Asian economies such as 68.9 percent in the Philippines, 51.7 percent in Malaysia, 46.4 percent in Singapore and 33.4 percent in South Korea (Table 4). It will be interesting to see whether China will be able to follow its Asian neighbours in terms of hi-tech sector development.

[16] Labour compensation shares over total R&D costs are estimated using data from OECD online database (SourceOECD.org).

[17] This is a nominal rate of growth calculated using data from YHT (2008).



Sources: YHI (2002, 2008).

Figure 7: Hi-tech Sector Value-added (in 1995 constant prices)

Implication for future economic growth

A precise assessment of the contribution of innovation to China's growth is controversial both technically and conceptually. The empirical literature is dominated by growth accounting exercises and has focused on the analysis of the traditional Solow-type innovation or total factor productivity (TFP) growth. Wu (forthcoming) reviews over 70 studies with more than 150 estimates of TFP growth rates and finds that TFP growth on average accounts for about one third of China's economic growth during the 1990s and the first decade of this century (Wu forthcoming). The same figure for more developed economies is, however, much higher. For example, according to Dougherty and Jorgenson (1996), productivity growth accounted for 49.8 and 57.6 percent of output growth during 1960-89 in Japan and Germany, respectively. Therefore, there is considerable scope for improvement in China's productivity growth in general and innovation in particular.

Table 4 Hi-tech Sector Exports in Selected Economies in 2007

Countries	% of Manufactured Exports	World Shares (%)
China	29.7	18.6
United States	28.5	12.7
Germany	14.2	8.6
Japan	19.0	6.7
South Korea	33.4	6.1
Singapore	46.4	5.8
France	18.9	4.5
Netherlands	25.7	4.1
Malaysia	51.7	3.6
United Kingdom	19.5	3.5
Mexico	17.1	1.8
Philippines	68.9	1.6
Brazil	11.9	0.5
India	5.3	0.3
Russian Federation	6.9	0.2

Sources: World Bank (2010).

The modest contribution of innovation to economic growth over the past three decades is consistent with the country's innovation conditions. As shown in the preceding sections, evidence at both the macro and micro levels illustrates that there is still a considerable gap between China and the advanced economies in terms of innovation resources and capacity. China is, however, catching up rapidly with developed economies in terms of its innovation capacity measured using various criteria such as the number of patents registered, scientific publications and citations and hi-tech commodity exports. The driving forces for the catch-up are the increasing R&D inputs in both capital and human resources. The catch-up will make it possible for the country to realise its innovation potential, which will be vital for China's sustainable growth in the coming decades. To reach this goal, several emerging issues must be resolved by Chinese policy makers.

First, in terms of aggregate investment in R&D, China is ahead of other countries at a similar stage of development and the country is also rapidly catching up with OECD economies. However, there are areas where China could do much better. For example, China's R&D intensity in the hi-tech sector is lagging behind the major players in the world (Table 5). In four of the five hi-tech sectors (with the exception of the aircraft and spacecraft sector), there is a huge gap in R&D intensity. Even in the aircraft and spacecraft industry, China's R&D intensity is about a half of those in Germany, France and the United Kingdom in 2007 (Table 5).

Table 5 Hi-tech Sector R&D Intensity in Selected Economies in 2006 (%)

Industries	China	US	Japan	Germany	France	UK	Italy	Korea
Manufacturing total	3.4	10.2	11.0	7.6	9.9	7.0	2.4	9.3
Hi-tech sector total	5.7	39.8	28.9	21.5	31.9	26.6	11.1	21.3
Pharmaceuticals	4.7	46.2	37.1	23.9	33.4	42.3	5.0	6.3
Aircraft and spacecraft	14.9	24.1	11.5	32.9	31.1	31.1	45.2	26.1
Electronic and telecommunication equipments	6.4	43.3	13.4	28.8	50.9	23.9	11.6	25.1
Computers and office equipments	3.8	34.7	na	14.9	27.7	1.4	8.4	14.2
Medical equipments and meters	5.2	48.3	31.9	13.6	19.0	7.8	6.7	10.3

Sources: YHT (2008, 2009).

Second, with the expansion of the R&D activities it is important not to neglect the quality of R&D in China. The preceding sections presented evidence of relative declines in investment in basic and applied research in recent years. This is also reflected in the small share of "invention" patents among total domestic patents in China. If this trend continues, China's long-term capacity in innovation, and hence the sustainability of economic growth in the future, may be compromised.

Third, the role of privately-owned enterprises including foreign firms in innovation should be strengthened through more stringent enforcement of intellectual property rights protection laws and regulations and the provision of incentives via appropriate innovation policies. As shown in the preceding sections, the enterprise sector plays the leading role in innovation in the world's major economies. Although China's privately-owned firms are expanding rapidly, in terms of innovation, they are lagging behind their state-owned counterparts, namely, the SOEs, not to mention privately-owned firms in other countries. This may be due to institutional constraints in China such as limited access to finance and government grants for non-SOEs.

Finally, there is considerable regional disparity in innovation. This not only contributes to China's overall regional disparity but is also detrimental to the diffusion of knowledge and technology within China. There should be institutional mechanisms to ensure a more even distribution of innovation resources across the Chinese regions.

Conclusions

In summary, China has made considerable progress in developing indigenous innovation skills and capacity over the last three decades. This trend has been strengthened through the implementation of the "2020 Program" of science and technology development since 2006. It also lays the foundation for the possible transformation of China's economic growth model from a resource-intensive one to an innovation-oriented model. China's investment in innovation has already grown rapidly, with innovation outcomes expanding as a consequence.

An important development in recent years is the expanded role of Chinese enterprises in innovation. Chinese firms are now the dominant R&D spenders and investors in the country. However, in terms of innovation-related firm characteristics, heterogeneity exists across firms with different ownership and scales as well as in different industries and locations. It is shown in this study that state-owned enterprises (SOEs) performed much better than foreign-invested firms and privately-owned Chinese firms as far as R&D propensity and efforts are concerned. This is a dilemma for China. As economic reform deepens, SOEs are under pressure to be privatised. In the mean time, non-SOEs (including foreign and indigenous private firms) are not ready to take risks associated with R&D activities. This situation calls for specific policies encouraging the participation of non-state firms in innovation, and improvement of the legal system to provide effective protection of IPRs in China.

This study has also demonstrated the gap between China and world's leading innovators. To close the gap, Chinese policy makers could pay more attention to several issues in the coming decades. First, while China is the world's largest exporter of hi-tech products, China's R&D intensity in the hi-tech sectors is lagging behind the world's major players. Second, as the role of enterprises in innovation is strengthened, there is the danger of neglecting basic and applied research, which is vital for the country's innovation capacity building in the longer term. Finally, both the quantity and quality of innovation investments and products should be monitored during the process of economic transformation. Growth should not compromise the quality of innovation.

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