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China, High or Low Tech Power ?

The Contrasted Picture of China's Scientific and Technological Capabilities

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Acknowledgments

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Introduction

China's rise as a global trading power and its sudden prominence in the world economy has given rise to a mixture of admiration and fear. An increasing number of countries, including both advanced and intermediary economies such as Mexico or South Korea, have experienced increased imports from China and tougher competition on international export markets. Moreover, since 2000, China has graduated from an export of labor-intensive low-tech products to a successful exporter of high tech products. Recently, China has become very attractive not only for production units, but also for R&D activities. As a consequence, an increasing number of countries consider China as a potential threat to their current scientific and technological position. In the United States, various estimates of China's achievements and potential have fuelled fears that the country will inevitably tilt global trade and technology balances in its favor, ultimately becoming an economic, technological, and military threat to the American leadership. The issue of economic and technological threat is also increasingly discussed in European countries. Similarly, although Korea benefits from market opportunities in China, Korean policymakers and industrial experts are worried about the threat from its large neighbor.

At the global level, worries about a rapid scientific and technological catching up of China are heightened by the simultaneous attractiveness of India for service and R&D offshoring. In the European Union, high wage countries also fear the increasing attractiveness of some new member economies for high tech activities. Recent examples of acquisitions of some well known brands by emerging multinationals from China have also contributed to the fear that the rapidly rising economy could be a threat to advanced countries.

These reactions to the economic development of China, however, are mistaken. They overlook both a number of weaknesses in China's economic "miracle" and the benefits advanced contries are reaping from the integration of China into the global economy. This paper discusses the opinion that China is rapidly upgrading its innovation capabilities and would thus pose a serious challenge to advanced countries in high tech industries. Part 1 examines China’s trade performance, which is impressive, in particular in some high tech sectors. It distinguishes Information and Communication Technologies (ICT) sectors from other high tech sectors and underscores the role of foreign affiliates in China’s trade performance. As production has become fragmented within global networks, export data is deceptive, or at least a very partial indicator of economic and technological performance. Part 2 underscores China’s rapidly increasing investment in R&D and tertiary education. It also assesses the contribution of foreign firms and international links to China’s scientific and technological resources. Part 3 discusses China’s R&D output. It first presents data on scientific publications and patenting. It then tries to give a general assessment of China’s technological capabilities by discussing a number of synthetic world rankings. These various output indicators rank China among emerging countries. Most of them are much smaller than China, which partially explains the discrepancy between such results and the common perception of China’s achievement. The conclusion considers the prospect of China’s technological take-off and discusses its innovation policies in relation with its integration into the global economy.

1. Is China (really) a Large Exporter of High Tech Products ?

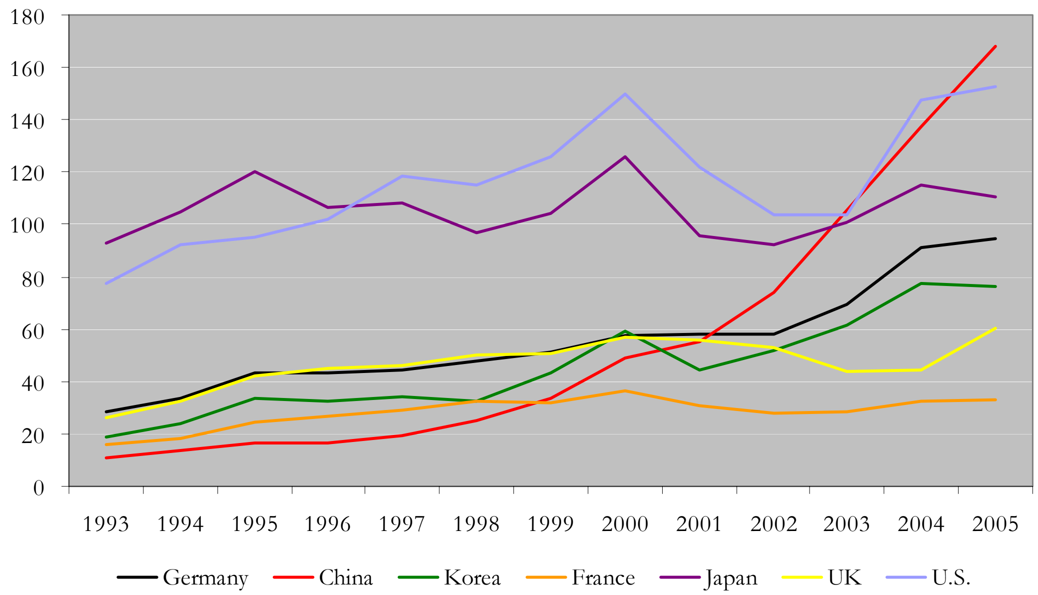
China's trade in goods as a percentage of GDP nearly doubled between 1990 and 2002, reaching close to 30%, which is high for such a large country. Moreover, China's exports have rapidly changed towards more technology intensive products and high-technology manufacturing has made a large contribution to export expansion. China's position in world trade is thus paradoxical: a labor-intensive country, it seems to perform particularly well in technology intensive exports. Rodrik (2006) has estimated that, at the beginning of the 2000s, its export bundle is that of a country with an income-per-capita three times higher than China's.

This section explores this paradox with a detailed analysis of China's trade in high technology products.

1.1 China has become the first exporter of ICT products

China has become the world first exporter of ICT.[1] Figure 1 shows that its exports have increased rapidly since in 2000 and have become higher than ICT exports from the U.S. This rapid growth contrasts with the stability of Japan's exports over the last decade. Sales by Germany, Korea and the U.S. have also increased substantially, but exports by China have more than trebled since 2000.

Figure 1. Main exporters of ICT, $bn, 1993-2005



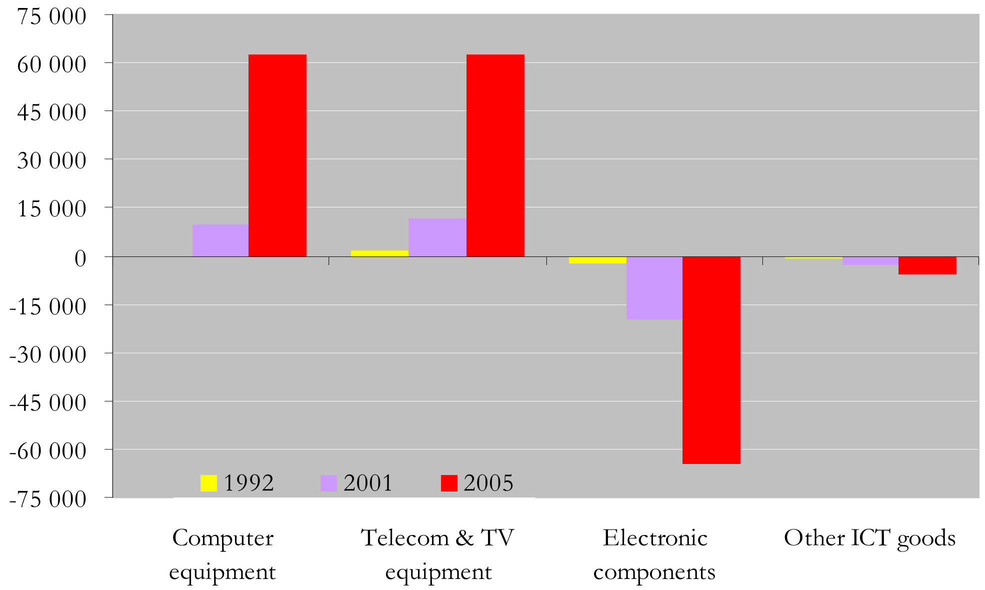
Source: SYSPROD-IFRI

China's share of world exports varies substantially across the different ICT sectors. China is the first exporter of electronic consumer goods, computers and telecommunication equipment, but has a more modest position in electronic components and instruments (SESSI 2005). Figure 2

[1] See Box 1 for the definitions of ICT and high tech products used to discuss trade data.

shows that China has a $bn 120 positive trade balance for the first three categories, but a $bn 60 deficit in electronic components. Since the early 1990s, the positive balance in final products has been increasing in parallel with the negative balance in components. Overall though, China has rapidly increased its positive trade balance over the last couple of years.

Figure 2. ICT Trade Balance of China, $ million



Source: SYSPROD-IFRI

Box 1. Definition of high technology and ICT sectors

Definitions used to calculate trade flows for "Information and Communication Technologies", as well as for "High Technology" products are the same as those used by studies conducted at OECD (OECD 2002). Calculations have been made from SYSPROD-IFRI database, using International Trade in Commodity Statistics (ITCS) classification.

ICT

Office, accounting and computing machinery; Insulated wire and cable; Electronic valves and tubes and other electronic components; TV and radio transmitters and apparatus for line telephony and telegraphy; TV and radio receivers, sound or video or reproducing apparatus etc.; Instruments and appliances for mesuring, checking, testing, navigating and other purposes except industrial process equipment.; Industrial process equipment.

High technology

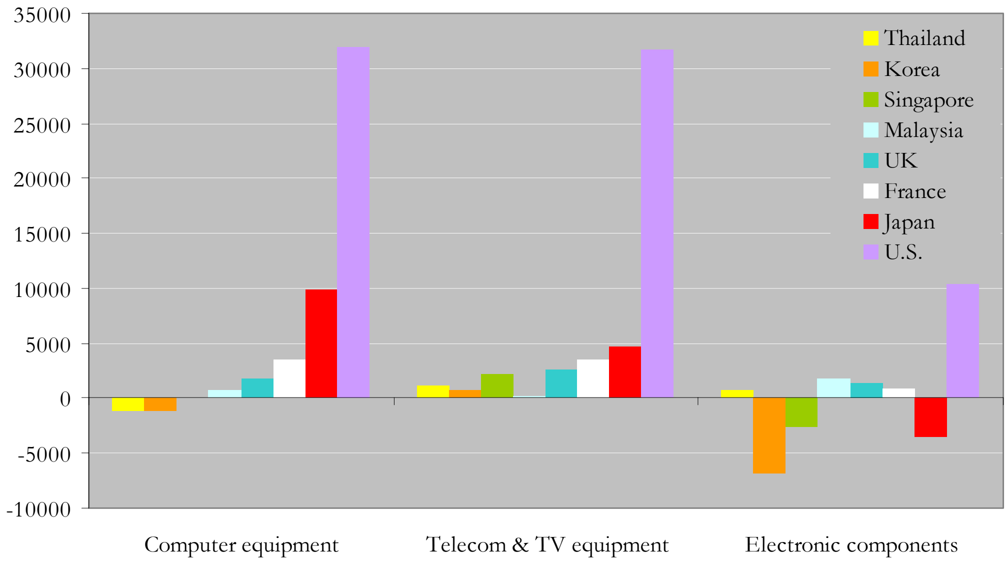
Office, accounting and computing machinery; TV, radio and communication equipment; Instruments (medical, optical...); Aerospace; Pharmaceuticals.

Figure 3 shows that China's positive balance in ICT equipment results from trade with advanced countries, especially the United States. The trade deficit in ICT components results from trade with Asian neighbors, especially Korea and Japan.[2] This trade pattern suggests that China imports

[2] Figure 2 is based on Chinese data and Figure 3 on partner countries' data. Japan's ICT deficit with China disappears when the trade balance is computed with Chinese data. As in the case of the U.S., the computation of trade through Hong Kong is different in the exporting and importing country.

ICT components for assembly, after which the finalised products are exported back to the rest of the world. The United States is the largest market for these exports from China, followed by the EU and Japan (Schaaper 2004).

Figure 3. Trade Balance of different countries with China by ICT product, $ million, 2005



Source: SYSPROD-IFRI

Table 1 supports the assembly hypothesis by showing the fundamental role of foreign affiliates in Chinese ICT exports. In 2003, foreign affiliates accounted for 55 percent of China's total exports, but that share was much lower for labor-intensive exports and much higher for technology-intensive exports (Gilboy 2004, Gaulier *et al.* 2005). Multinationals are responsible for nearly all Chinese exports of computers, which have become a major export from China. Taiwanese and Korean firms have for example largely relocated the production of notebook computers to mainland China (Bergsten *et al.* 2006). Table 1 shows that in the case of electronic components, the role foreign affiliates has actually increased over time. It has decreased somewhat in consumer goods, which is the least R&D intensive ICT sector.

Table 1. Foreign affiliates in China's exports of ICT products, in %

	Share of foreign affiliates in exports		**Share in total exports, 2003**
	1998	**2003**	
Computers	99	97	15
Electronic components	81	92	5
TV et other home equip.	96	78	5
Telecom equipment	96	91	4

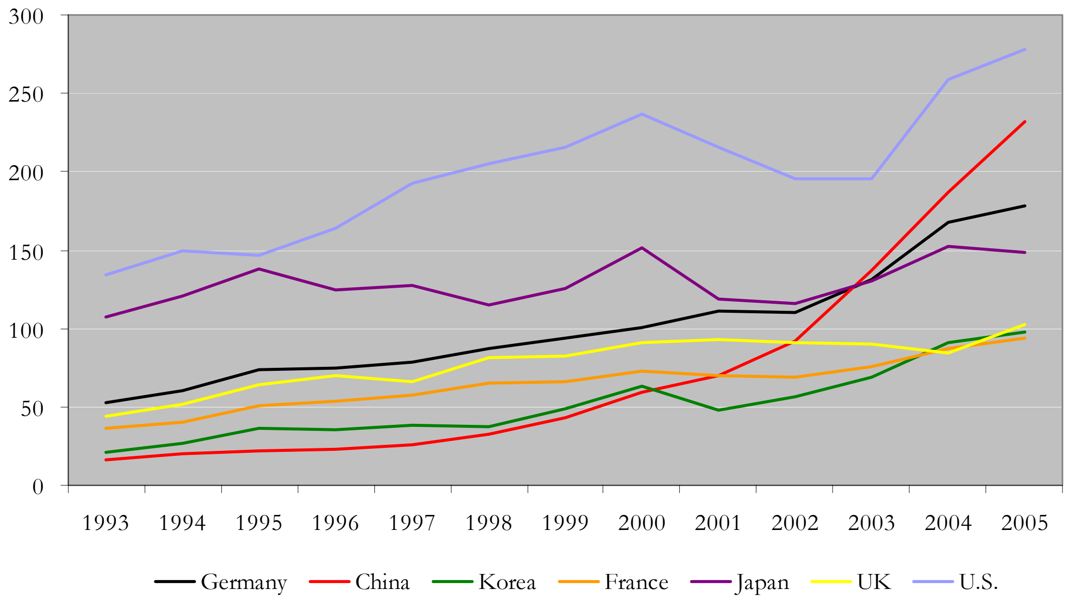
Source: Adapted from Tong (2006)

Figure 1 shows that China is the first exporter of finished ICT products. But more detailed data on China's trade patterns actually suggest that it focuses on assembling imported electronic components in foreign affiliates, which then export the finished goods. China would thus more accurately described as the first exporter of labor-intensive assembly work in ICT.

1.2 China is not specialized in high tech manufacturing

China's exports of high tech manufactures have been very dynamic since the late 1990s, but the United States remain the first world exporter of high tech products (figure 4). This may be explained by the focus of Chinese high tech exports on ICT.[3]

Figure 4. Main exporters of high tech manufactures, $bn 1992-2005



Source: SYSPROD-IFRI

Since 2000, China has rapidly increased its world market share in ICT products, but its performance has been much less impressive in other high tech sectors. Figure 5 shows that China is a weak exporter in pharmaceuticals and aerospace in particular. China's manufacturing exports are concentrated in two types of sectors: labor-intensive goods such as textile and clothing on the one hand and ICT products for which low-cost assembly is a competitive advantage on the other hand. Moreover, Chinese ICT exports to the U.S. are concentrated in mass-market products, such as notebook computers, mobile phones and DVD players (Bergsten *et al.* 2006).

The driving role played by ICT assembling explains the simultaneous growth of exports and imports of ICT by China (figure 6). Imports of semiconductors and microprocessors, which are embedded in ICT products, have soared since the 1990s. Over the last couple of years export of high tech products have nevertheless become even more dynamic than imports, resulting in a trade surplus. In this respect, total high tech trade (figure 6) is consistent with ICT trade (figure 2).

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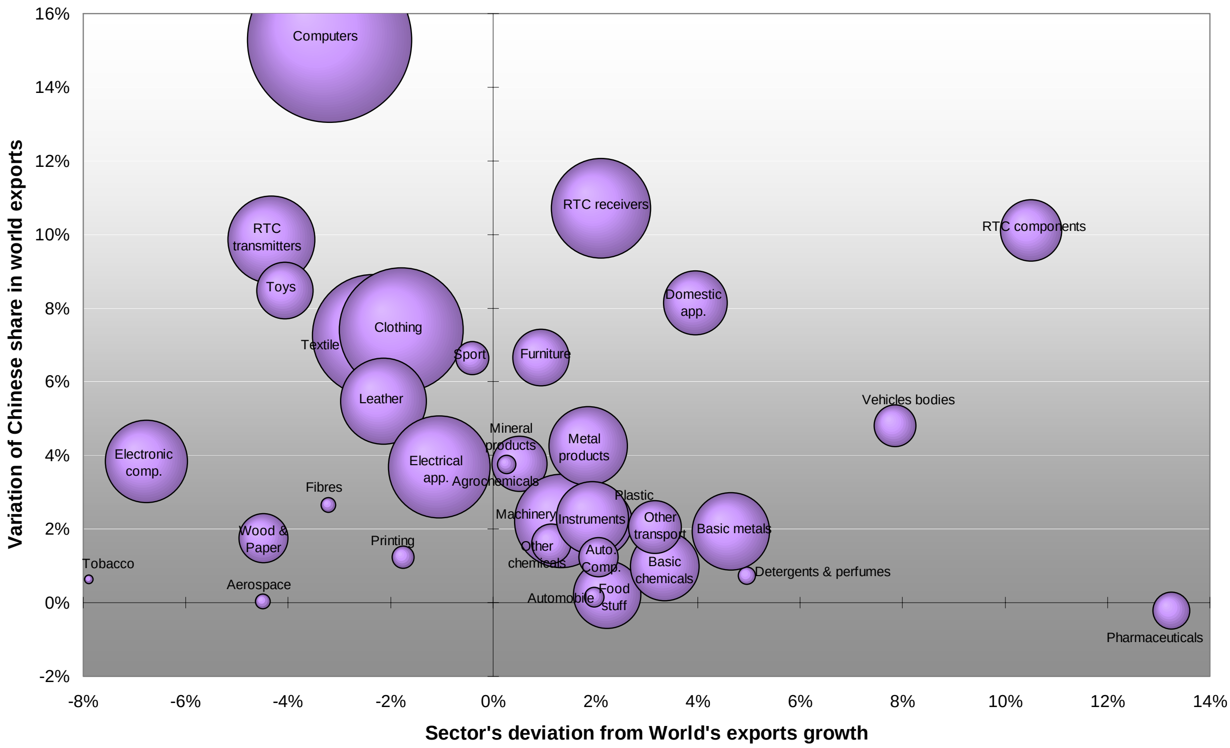
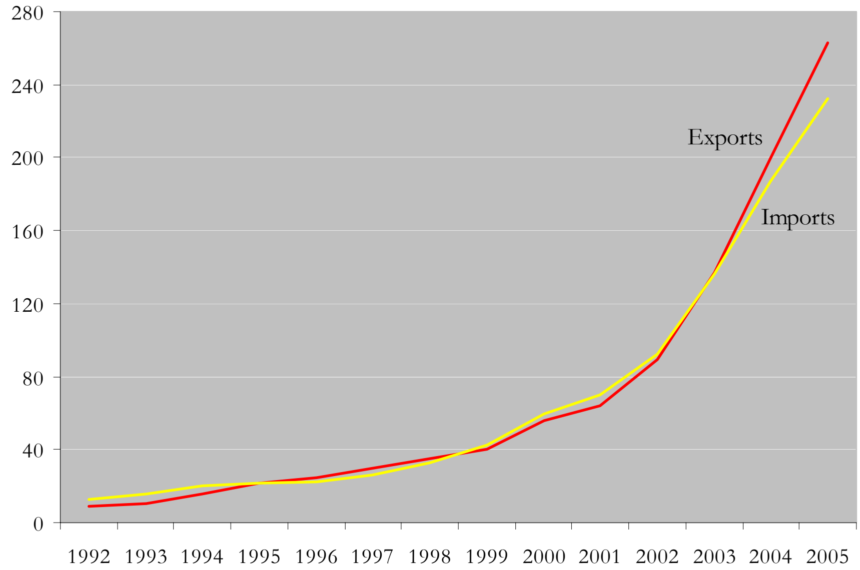
[3] Using a slightly different definition of "high technology" products ("advanced technology") Bergsten *et al.* (2006) also underscore the focus of China's high tech exports on ICT.

Figure 5. Dynamics of Chinese manufacturing exports, by sector, 2000-2004



The size of the bubble is proportional to the share of the sector in China's exports
Source: Computed from SYSPROD-IFRI data base

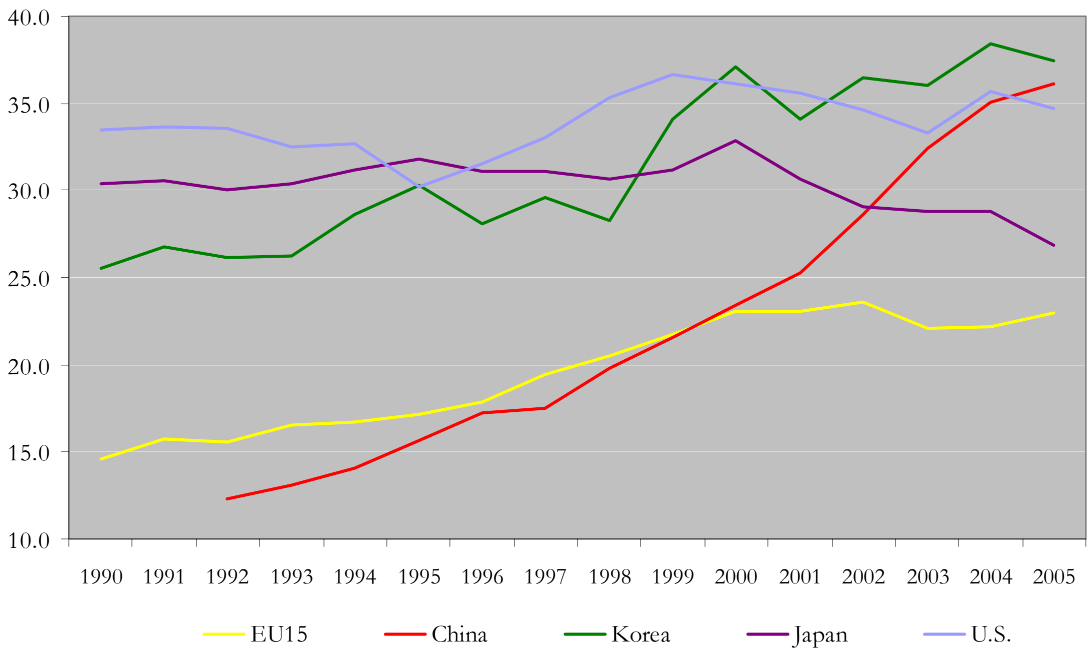
Figure 6. China's High-tech exports and imports, 1992-2005, $bn



Source: SYSPROD-IFRI

Dynamic ICT exports have been fuelling the increasing share of high tech products in China's manufacturing exports. Figure 7 shows that high tech products now account for a similar share in Chinese and American exports.

Figure 7. High-technology exports as a percentage of total manufactured exports



Source: SYSPROD-IFRI

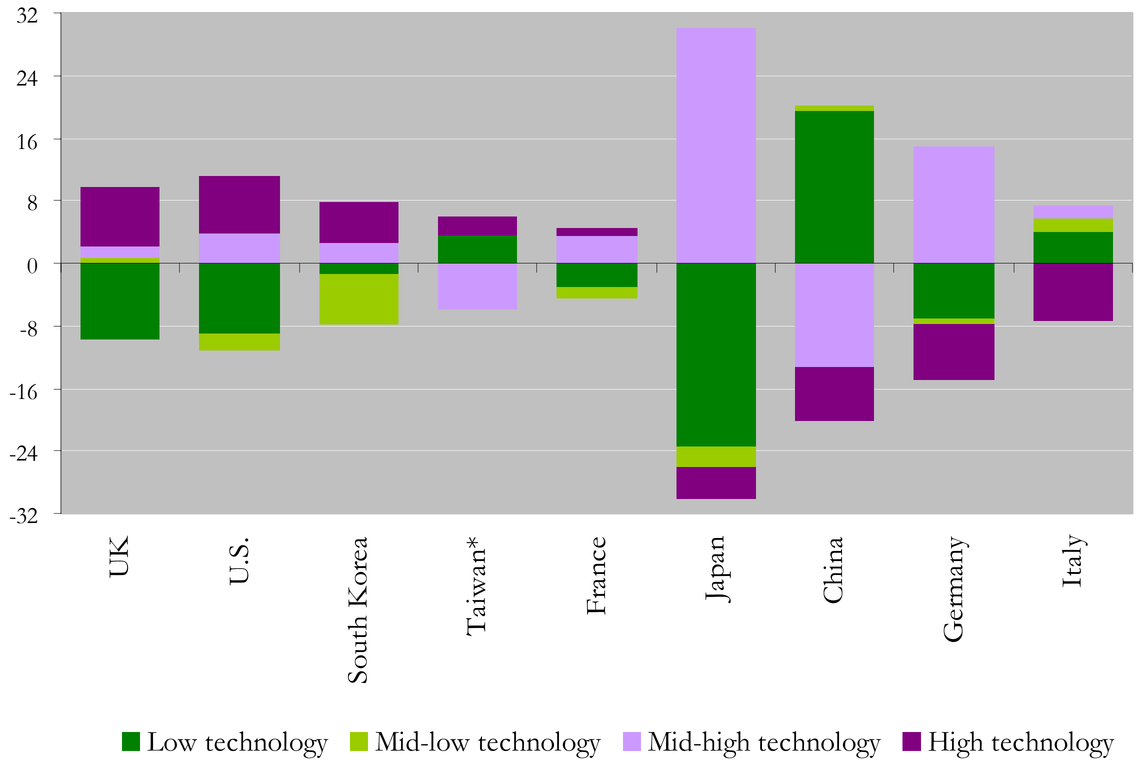
China's impressive performance in high tech exports has attracted much attention and a number of authors have examined the possible causes for the country's competitiveness in technology intensive products (Adams *et al.* 2004; Rodrik 2006). The role of foreign affiliates is usually acknowledged, but not fully taken into account. Figure 8 shows that when both exports and imports are used to compute the contribution of high tech industries to the trade balance,[4] China's dependance on imported inputs clearly shows. Figure 8 is based on manufacturing trade only, so that it can not be used as an indicator of comparative advantage, but it clearly shows that China remains strongly specialized in low tech products. The contrast is particularly sharp with the UK and the U.S., which exhibit the highest specialization in high tech products. Besides, it may be interesting to notice that these two countries are among the most specialized in services, as opposed to manufacturing (Miotti and Sachwald 2006). Figure 8 also shows that Japan's and Germany's manufacturing trade surpluses are pulled by mid-high tech products (such as cars and machines). High tech products contribute positively on the contrary to South Korea and Taiwan trade balance.

Figure 9 shows that the contribution of high tech to trade balance has substantially changed over the last decade for some countries. The manufacturing specialization of Korea and the UK in high tech has increased most, while that of Japan has dramatically decreased. China's specialization has on the contrary remained negative, despite the dynamism of its ICT exports.

[4] The indicator of contribution to the trade balance of product *i* is defined as :

$$CTB_i = \frac{100}{(X+M)/2}\left[(Xi - Mi) - (X - M)\frac{(Xi + Mi)}{(X + M)}\right]$$

Figure 8. Contributions of industries to the trade balance° as a percentage of manufacturing trade by technological intensity, 2005

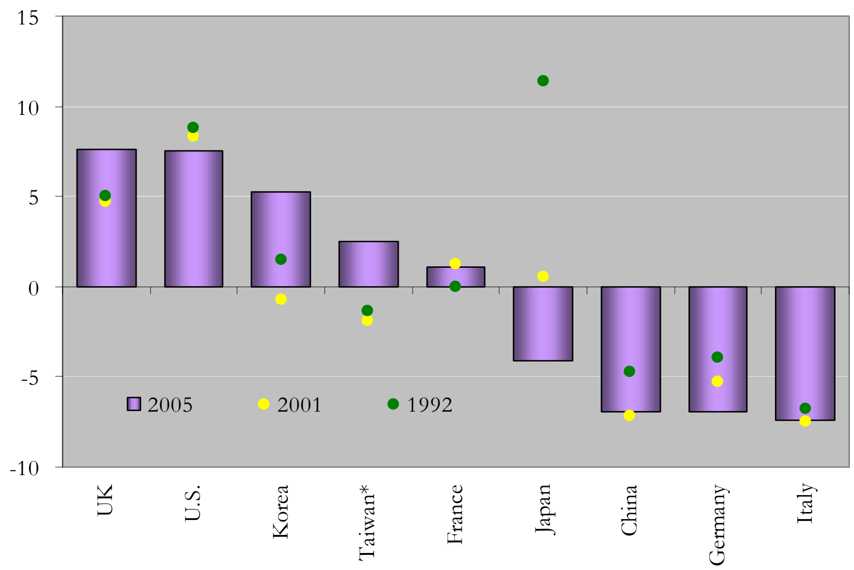


° $CTB_i = \frac{100}{(X+M)/2}\left[(Xi - Mi) - (X - M)\frac{(Xi + Mi)}{(X+M)}\right]$, based on data in current USD and ordered by size of the contribution of high tech sectors

* 2004

Source: SYSPROD-IFRI and UNCTAD for Taiwan

Figure 9. Contribution of high-tech industries to the trade balance as a percentage of manufacturing trade, 1992-2005



Source: SYSPROD-IFRI

Our detailed examination of China's trade solves the paradox raised by Rodrik (2006). China's export performance is actually driven by the country's low labor cost, which has attracted assembly operations by ICT multinationals. As a result China's imports of ICT components have increased as dramatically as its exports. China is also a very weak exporter of other high tech products, such as pharmaceuticals. Overall, China is, logically, specialized in low tech production activities rather than in high tech activities. Increasing fragmentation of production explains that China can be specialized in labor-intensive activities as part of the value chain of technology-intensive products.

2. R&D resources in China: Domestic and Foreign Contributions

China's growth rates in R&D inputs is impressive, but start from a very low base. As a consequence, China's R&D intensity remains relatively low. This part also shows that China's R&D resources are not as sophisticated or close to the scientific frontier as in more advanced countries.

2.1 Rapid increase in R&D spending

Table 2 compares R&D spending for the countries that represent most of world R&D spending. Gross domestic expenditure on R&D (GERD) is expressed in terms of purchasing power parity. PPP rates for R&D inputs not available, but salaries represent a large part of R&D spending and it seems relevant to use PPP conversion rather than use current dollars to compare countries.[5] Bergsten *et al.* (2006) consider that this procedure leads to an overestimate of China's R&D spending, in particular because prices and salaries tend to be higher in urban areas, where R&D activities are concentrated. In table 2 China ranks third, behind the U.S. and Japan, for total R&D expenses. Table 2 also shows that R&D spending grows particularly fast in China. As a result, chinese expenses increased from 18% of American expenses in 2000 to 32.8% in 2004. Based on these recent trends, OECD (2006) has forecasted that China would spend just over USD 136 billion on R&D in 2006, just over Japan's forecast of USD 130 billion. China's R&D spending is of course much smaller when expressed in current dollars, and ranks much lower in international comparisons. Using current dollars, Bergsten *et al.* (2006) indicate that in 2005 China spent only one tenth as much as the U.S. on R&D. Table 2 also shows that China's R&D intensity, while still relatively low, increases rapidly. In 2004, it was 1.44% (table 2), but since China's GDP has been reestimated to better take into account service production, the figure has decreased. According to the latest available estimation of R&D intensity from OECD (2006), China's R&D intensity is 1.2%.

There has been a huge expansion in the number of researchers since the late 1990s; China counts now more researchers than Japan, and is coming closer to the U.S. (table 2). In 2004, the number of researchers in China is relatively much higher than its R&D spending, reaching 69% of that of the United States. As for R&D spending nevertheless, the ranking is quite different for the number of researchers relative to employment, which is still very low in China. Besides, Table 2 shows that the ratio of researchers is particularly low in China; it is comparatively much lower than R&D intensity.[6]

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[5] In China, a large number of graduate students act as low-cost, high-quality research workers, which would increase the country's PPP for R&D beyond its average value for the economy (Seong *et al.* 2005).

[6] One possible explanation could be the relatively large share of the population in agriculture.

Table 2. R&D resources and R&D intensity in the largest R&D spending countries

	GERD 2004 Million PPP$	GERD as a % of GDP[1]	Number of researchers 2003	Researchers per 000 employment[2]
US	312,535.4	2.68	1,334,628	9.6
Japan	112,714.7	3.15	675,330	10.4
China	102,622.9	1.44	926,252	1.2
Germany	58,687.6	2.49	268,943	6.9
France	39,740.3	2.16	192,790	7.7
UK	33,705.7	1.88	157,662	n.a.
Korea	24,273.7	2.63	151,254	6.8
Canada	19,326.5	1.93	112,624	7.2
Russia	16,457.8	1.29	477,647	7.1
Taiwan	13,493.6	2.45	67,599	7.1
Spain	11,071.8	1.05	92,523	5.2
Sweden	10,340.0	3.98	47,836	11.0
Australia	9,608.6	1.69	73,344	7.8
Netherlands	8,707.4	1.80	43,539	5.2
Israel	7,597.7	4.46	n.a.	n.a.
Belgium	5,802.9	1.89	32,237	7.8
Austria	5,889.5	2.26	24,124	5.8
Denmark	4,374.0	2.62	25,546	9.3
Norway	2,961.1	1.75	20,989	9.1
Poland	2,471.6	0.56	58,595	4.5
Singapore	2,659.7	2.25	21,359	9.8
EU-25	211,252.8	1.82	1,169,633	5.8
Total OECD	**686,649.7**	**2.26**	**3,563,793**	**8.3**

1. 2004 or latest available year ; 2. 2003 or latest available year

Source : OECD, *Main Science and Technology Indicators* 2005

Expenses in basic research may be considered as an indicator of investment in long-term innovation capabilities and as a proxy for frontier research activities. Advanced countries spend between 15 and 20% of their R&D expenses in basic research activities (OECD 2005). China's R&D capabilities are more heavily focused on development. In 2002, 5.7% of its expenses went to basic research, compared with more than 18% for the U.S. and 13.7% for Korea (Seong *et al.* 2005). According to availabe data, in 2004, the United States spent 0.5% of its GDP on basic research, as opposed to less than 0.1% for China:[7] five times less, while China's R&D intensity is more than half that of the U.S.

R&D expenditures and researchers are concentrated in the public sector and business R&D is relatively less important than in many R&D intensive countries. Besides, the Chinese industrial sector tends to spend more resources on design activities than on invention and relies on external sources of technology more than on its own innovations. This may be related to the above analysis of trade in high tech sectors and of the role of foreign companies in these sectors. Foreign affiliates are the most active actors in high tech industries in China, and especially in electronics, but they tend to rely on their parent company for their technology inputs. In 2003, foreign affiliates represented 23.7% of business R&D expenditures in China (UNCTAD 2005).

[7] Estimate based on data from OECD (2005), allowing for a small increase in the proportion of basic R&D in China.

This is relatively high compared to countries such as the United States (14.1%) or Germany (22.1%) and much higher than in Japan and Korea. But R&D intensity in foreign firms in China is lower than in domestic firms.[8] Moreover, their R&D expenses are focused on development activities for adaptation to the local market in the various sectors in which foreign firms have substantial operations.[9] China's very large potential market has attracted foreign production activities, which in turn have pulled R&D units. This trend has been further promoted by specific chinese policies.

2.2 A large pool of talents

China has introduced major educational reforms in the late 1990s and has substantially increased public investment in education. The education budget has increased from 2.5% of GDP in 1997 to 3.3% in 2002 (Seong *et al.* 2005). Besides, China has set up ambitious goals for its universities, a number of which have been merged in order to concentrate resources. A major endeavour is the creation of 100 Key Universities, which should emulate the American model of research universities.[10] Since 1995, the country allocates large amounts of funds to the 100 Key Universities. They represent only 10% of the Chinese universities, but their role in education and R&D has been increasing rapidly and they account for a much larger share of MSc and PhD students. They also represent a major force in China's basic research and generate numerous high-tech spin-offs.

The number of students enrolled in tertiary education has been increasing rapidly. Between 2000 and 2004, the number of students in China was multiplied by 2.6, reaching 19.4 million.[11] As a result, the absolute number of enrolments and graduates from tertiary education in China match the number in the U.S. and the EU, where rates of growth are much slower. Table 3 shows that, although the total number of students is impressive, only a small part the Chinese population has a tertiary education (a parallel with researchers in table 2).

Table 3. Students enrolled in tertiary education, 2004

Country	Total enrolment in tertiary education	Tertiary students per 100,000 hab.
China	19,417,044	1,494
United States	16,900,471	5,776
India	11,852,936	1,107
Japan	4,031,604	3,146
Mexico	2,322,781	2,226
United Kingdom	2,247,441	3,791
Germany	2,185,224	2,660
France	2,160,300	3,600

Source: UNESCO

[8] In the sample studied by K. Motohashi (2006) (22,000 firms each year between 1998 and 2002) the ratio of R&D to sales was nearly 1% for domestic firms and 0.4% for wholly-owned foreign affiliates.

[9] For discussions of foreign R&D in China and the focus on development activities in emerging countries, see (Walsh 2003, Zedtwitz 2004, Motohashi 2006, Sachwald 2007).

[10] An "Academic ranking of world universities" has been designed by one Jia Tong university in Shanghai in order to identify the world best universities and to rank the position of Chinese universities (http://ed.sjtu.edu.cn/ranking.htm).

[11] Data from UNESCO.

As technical work and engineering are being increasingly outsourced to emerging countries, the growing talent pools in China and India have attracted keen attention. The underlying data used to illustrate the trends in higher education however should be examined closely. This data issue may be illustrated by two examples: enrolments in PhD programs and graduation from engineering programs.

China's level of enrolments in advanced research programs such as PhDs is still low (Schaaper 2004). Richard Freeman (2005), considers that the number of students entering PhD program increases so rapidly in China that the country could produce more PhDs than the U.S. by 2010 – as opposed to a ratio of 1 to 3 in 2001. Such catching up though would require China to keep up with the very rapid rate of increase in PhD enrolment it has experienced over recent years. It would also require a good graduation rate. Finally, such comparisons beg the question of the quality of doctorate education.

Gereffi and Wadhwa (2006) have underscored the difficulty to compare seemingly equivalent degrees between the United States, China and India. Their study focuses on engineering and computer science and information technology degrees. Difficulties arise first because the definition of an engineer and the content of curricula differ very substantially across countries. Detailed data is also not always available from the Chinese and Indian institutions. According to Gereffi and Wadhwa (2006) the number of engineers produced in China and India is much closer to that produced by the U.S. when compared on a level playing field, than what press reports suggest.[12] Table 4 shows that India and China produce relatively less bachelor degrees and relatively more short-cycle degrees than the U.S. Besides, as for other indicators, these total numbers should also be considered in proportion to the total population and needs of the Chinese or Indian economies. The demand for skills in public service, general management and education will remain high in China and will constrain the allocation of massive human resources to high tech sectors.

Table 4. Engineering degrees in the U.S., China and India, 2004

	United States	China	India
Bachelors and Subbaccalaureate Engineering, Computer Science and IT Degrees	**222,335**	**644,106**	**215,000**
Bachelor Degrees	137,437	351,537	112,000
- Engineering (exl. CS and electrical)	*52,520*	-	*17,000*
- Computer Science, Electrical and IT	*84,917*	-	*95,000*
Subbaccalaureate Degrees	84,898	292,569	103,000
- Engineering (exl. CS and electrical)	*39,652*	-	*57,000*
- Computer Science, Electrical and IT	*45,246*	-	*46,000*

Source: Gereffi and Wadhwa (2006)

These estimates may be supplemented with qualitative accounts from managers of foreign affiliates. According to a survey conducted by Mc Kinsey, China suffers from a "supply paradox": desptite its apparently vast supply of graduates, it actually produces only a small number of young

[12] The authors mention typical articles stating that in 2004, the US produced 70,000 undergraduate engineers, against 600,000 in china and 350,000 in India. More recently, *The Economist*, in an interesting and documented survey writes that India produces every year "2.5m university graduates, including 400,000 engineers and 200,000 IT professionals" ("The battle for brainpower", Oct. 7 2006, p.8)

professionals suitable for work in foreign companies.[13] For example, Chinese applicants for engineering jobs have had little practical experience in projects or teamwork as the educational system focuses on theory. Interviews with managers of foreign R&D centers in China consider that Chinese young professionals have a good theoretical background and are fast learners, but lack management and language skills.[14] As a consequence, they need further training before they can be fully operational.

In order to increase the number of trained researchers and engineers working on its territory, China has also been pursuing policies that promote a "reverse brain drain". The government has introduced various policies to facilitate repatriation and resettlement, including preferential treatment for housing and research, specific fellowships, better dissemination of information, etc.[15] As a result, since the late 1990s, an increasing number of Chinese students have returned from OECD countries, and particularly from the U.S. In 2004, 25,000 students returned to China (Zweig 2006). However, since an increasing number of young Chinese go to study abroad, the proportion of returnees has not changed much. Returnees are nevertheless sufficiently numerous to represent a substantial proportion of researchers in some universities and research institutes (Zhou and Leydesdorff 2006). According to various surveys, returnees tend to be more competent and better trained than the researchers that stayed in China, but the best researchers usually pursue their career abroad (Zweig 2006). Returnees nevertheless contribute to the quality of research in China and to technology transfer when they work in the private sector. The number of returnees should keep increasing as it is mainly motivated by sustained economic growth in China. Government policies will also help as they have created a favorable climate and additional incentives for returnees. Further reforms may however be necessary to stimulate the creation of companies by returnees and increase technology transfer (Zweig 2006).

3. A Small but Rapidly Increasing R&D Output

China's R&D has increased very rapidly over the last decade. Its performance for both scientific publications and patents is impressive, but China still makes a small original contribution to world R&D output. The overall evaluation of its S&T capabilities should thus be based on a varaiety of indicators and try to take into account both stock and flows data.

3.1 Scientific publications

Publication of papers in scientific journals is considered as an indicator of basic science capacity and is often used in comparative studies. Over the last decade, the number of scientific publications with a Chinese address has grown exponentially. In 1999, China was in the 10th position in terms of scientific publications and in 2004 it had reached the 5th position (table 5). Korea has also experienced a significant growth of its share of world publications, but China has been the only country with an exponential growth. The share of China varies substantially according to disciplines, with strong points in physical sciences and weak points in life sciences. Its share of world scientific publications is above 10% in materials science and physics (Stembridge 2006). Besides, a substantial share of the overall growth in China's publications may

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13 Results rely on interviews with 83 human-resources professionals (Farrell and Grant 2005).

14 Interviews conducted by the author in China in october 2006.

15 National policies are supplemented by specific schemes from local authorities.

be attributed to the thousands of papers from laboratories in the United Statsed that are co-authored by visiting Chinese reasearchers and students.[16]

Table 5. World share of scientific publications, 1993-2004 in %

	Korea	France	China	FRG	UK	Japan	USA	EU-15
1993	0.18	5.98	1.69	7.45	8.89	8.19	34.73	33.78
1994	0.58	5.99	1.70	7.54	8.97	8.57	33.66	34.12
1997	1.16	6.31	2.66	8.32	8.73	8.98	31.94	35.72
2000	1.76	6.31	3.89	8.69	9.22	9.49	30.93	36.55
2003	2.43	6.10	5.51	8.35	8.46	9.40	30.68	35.96
2004	2.70	5.81	6.52	8.11	8.33	8.81	30.18	35.18

Source: Zhou and Leydesdorff (2006)

Increased funding for R&D seems to have been quite efficient in terms of scientific publications. Over the last decade, China's share of world publications has grown proportionally with the increase in R&D investment (Zhou and Leydesdorff 2006). In 2002, China published twice as many science papers as Korea, while it only invested half as much in basic science. Seong *et al.* (2005) attribute the apparent scientific productivity of China to the large pool of students and researchers, as well as to the stock of past investments and accumulated knowledge in some basic science areas. Zhou and Leydesdorff (2006) also show that China's performance has been remarkable in the emerging field of nanoscience and nanotechnology. It started research later than the major countries, but made a large effort and increased its share of world publications rapidly. According to various bibliometric indicators, China appears in second position behind the United States with an 8.3% share of the world publications in nano-relevant fields, as opposed to 6.5% of publications for all fields (table 5). Porter *et al.* (2002) have also found that China was in a relatively strong position in a set of emerging technologies, including software, computer hardware, communication technologies, advanced materials for computing /communication technologies and biotechnology. According to their study, in 1999, China ranked 5th for publications in these fields. Based on these rankings, they identified three groups of countries: superpowers (U.S. and Japan); research powerhouses (Germany, UK, China, France); strong players (Italy, Korea, Canada, Russia, Taiwan).

The citation rate of Chinese papers has also been increasing exponentially during the last decade, but remains relatively low (Zhou and Leydesdorff 2006). Table 6 shows the average number of citations per paper for the countries with the largest number of publications. It underscores a large gap between advanced countries and China. A number of bibliometric studies consider that the share of the most highly cited papers is the most important measure of a country's influence in science (King 2004, Dosi *et al.* 2005). China has a particularly low rate of highly cited papers, but its performance has also substantially increased on this indicator (Zhou and Leydesdorff 2006). Between 1993-97 and 1997-2001, China's share of top 1% of highly cited publications increased from 0.44% to 0.99% (King 2004). Over the period, Ireland, India, South Africa, Singapore and South Korea also experienced a strong increase in their share of highly cited publications.

[16] Mu-Ming Poo, head of the Institute of Neuroscience in Shanghai, quoted in *Nature* (9 sept. 2004).

Table 6. World rankings of countries for papers catalogued by SCI in 2003

Rank	Country	Number of papers	Average citations per paper
1	United States	2,705,652	12
2	Japan	713,542	7
3	Germany	655,586	9
4	United Kingdom	598,470	10
5	France	484,291	9
6	Canada	358,007	10
7	Italy	310,557	8
8	Russia	285,856	3
9	China	236,996	3
10	Australia	211,549	8
16	South Korea	111,406	4

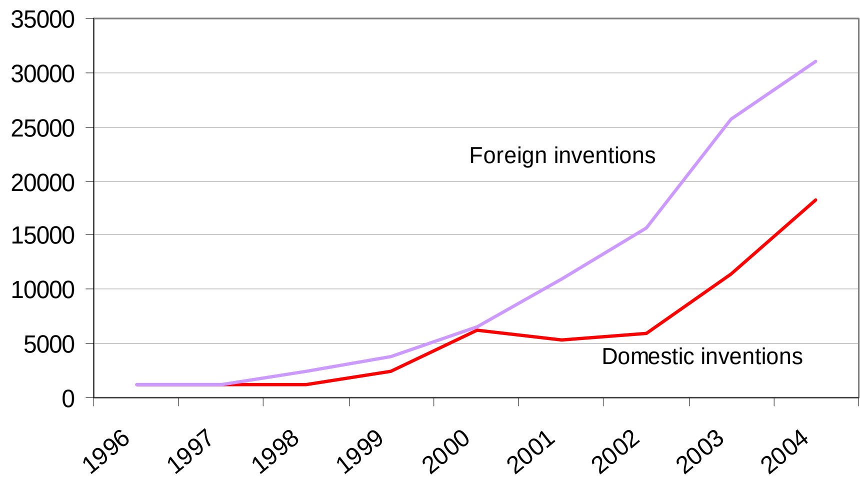
Source: Adapted from Seong *et al.* (2005)

Bibliometric studies thus give a nuanced evaluation of the Chinese scientific system. Scientific publications have kept pace with fast increasing R&D inputs. As a consequence, China has become a major player in the production of scientific papers at a fast pace by historical standards. The citation rate of Chinese papers however still lags far behind that of advanced countries and is also lower than that of some emerging countries.

3.2 Chinese and international patenting

Since 2000, China has been very active in patenting. In the case of invention patents, as opposed to utility and design patents, figure 10 shows that the surge has been particularly remarkable for foreign firms (the surge is more similar among foreign and domestic firms for applications). As a result, the proportion of patents owned by foreign residents is substantially higher for China than for the Triad economies (Schaaper 2004). A large share of these foreign owned patents invented in China is held by US institutions and to a lesser extent by EU institutions. Besides, Chinese patents also result from cooperation between Chinese and foreign co-inventors.

Figure 10. Number of Chinese invention patent grants, 1996-2004



Source: China's National Bureau of Statistics, www.stats.gov.cn

Hu and Jefferson (2006) have explored the different hypotheses that could explain China's patent explosion.[17] R&D intensification is a likely driving force, but is not supported by the data, which shows a low patents-R&D elasticity (by OECD standards). This elasticity is nevertheless higher for domestic firms, which supports the perception that foreign R&D aims at supporting local customization.[18] As a result, foreign patent applications may simply aim at Chinese legal protection for patents invented elsewhere. Increased foreign investment explains a small share of the total increase in patenting, but has an impact on both domestic and foreign firms. Competing with foreign firms has increased the awareness of Chinese firms of the strategic value of patents and some may increase their patent propensity in order to try to exploit loopholes in China's intellectual property protection (Hu and Jefferson 2006).

Figure 10 shows that foreign inventors have reacted more quickly than domestic inventors to the amendment to the patent law in 2000 and to China's entry to the WTO in 2001. The combined year effects of 2000 and 2001 explain almost 70% of the increase in patenting from 1995 to 2001 in the estimates conducted by Hu and Jefferson (2006). A more patent-friendly legal environment thus emerges as an important explanation of China's patenting boom since 2000. Further economic reform, with an increased role for private firms, more R&D investment and a stronger legal system should increase further returns to patenting. This should be clearly the case for invention patents, which have not been studied specifically so far.

Chinese-owned patents abroad have also increased rapidly since the late 1990s, but the share of China in international patenting remains tiny. Between 1999 and 2002, China had nearly doubled the number of triadic patent families it filed, from 75 to 144.[19] This remains very small compared with the largest patenting countries, the U.S. (18,324), Japan (13,195) and Germany (7,271). This is also modest compared with Israel (328), but higher than Taiwan (102). The number of U.S. patents granted to Chinese inventors has increased fivefold between 1993 and 2003, but also remains modest. In 2003, China ranked 21st in terms of U.S. patents granted to foreigners with a mere 0.3% of the total, while Taiwan ranked third with 6%, Korea fourth with 4.9% and India nineteenth with 0.4%.[20] International patent statistics thus suggest that China still enjoys relatively low innovation capabilities. This dovetails with the low proportion of invention patents of Chinese firms registered by CSIPO (China State Intellectual Property Office) – as opposed to model and design patents. Patents per million population, rather than the total number of patents, is also low by international standards (27th position, WIPO 2006). China's large population weighs on this indicator and its performance is stronger for patents per billion PPP dollars (17th) as well as for patents relative to R&D spending (11th).

3.3 Overall assessment of China's S&T capabilities

Different indicators paint a contrasted picture of China's scientific and technological capabilities. The various indicators considered above reveal four sets of oppositions that explain the different assessments circulating about China's S&T capabilities.

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17 They estimate a patents production function on a large sample of firms between 1995 and 2001. Unfortunately, their data does not distinguish between invention patents, utility model and design patents.

18 As discussed above in section 2.1.

19 OCDE "triadic patent families" data base aims at identifying patents of international value, as they are filed in the U.S, in the EU and in Japan. Data on triadic patents are from OECD (2005).

20 Calculations from *Science and Engineering Indicators 2006*.

First, China's ranking often depends on whether the analysis relies on size indicators or intensity indicators. China is the third country for total R&D spending and the second for the number of researchers, but it ranks much lower for R&D intensity or the proportion of researchers in employment.

Second, quantity and quality indicators are also often at odds. This is the case in the fields of tertiary education, patenting and scientific publications. We saw that the word "engineer" has a different meaning in Chinese and U.S. data and that the number of publications should be supplemented with indicators of citations to assess the contribution of China to world science. Similarly, since basic research represents a small share of R&D spending in China, total spending or even R&D intensity may be somewhat misleading in comparisons with more advanced countries.

Third, stock and flow indicators also tend to diverge. China is an emerging country with little cumulated investment in science and technology. As a consequence, its R&D input and output are still relatively small. China is however very dynamic, with high rates of growth on many economic and social indicators. Besides, China has made science and technology the cornerstone of its economic development since the 1980s and public investment strengthens R&D infrastructure and funding. As a result, a number of R&D input and output indicators experience impressive rates of growth.

Fourth, China's performance appears different according to the borders given to Chinese S&T capabilities. China is a quite open economy, with a high rate of trade openness and dynamic inward foreign direct investment. As a result, foreign affiliates have been major contributors to Chinese exports. Part 1 showed that foreign affiliates tend to be the main drivers of the extraordinary export performance of China in ICT markets. The above discussion has underscored the large contribution of foreign companies to the recent patent surge in China. It also seems that a number of China's publications may be attributed to papers from laboratories in the United Statsed that are co-authored by visiting Chinese reasearchers. These interactions with foreign contibutors to the Chinese innovation system are welcome, but the degree of integration with the local capabilities may still be quite limited.

Summary indicators of scientific and technological capabilities have been recently developed to compare countries at different levels of development. They typically take into account indicators of R&D input and output, as well as data on technology infrastructure. In particular, they include indicators of ICT diffusion. They have similar objectives, but use somewhat different sets of data and follow different methodology. It is thus interesting to examine China's ranking to see whether it is consistent across different summary indicators.

Table 7 compares four such indicators. They all include data on R&D spending, tertiary education and patent filing. They all include data on ICT diffusion, except for the RAND indicator. The latter is the only one to take scientific publications into account. Overall, it is the most "science oriented" indicator. The WEF indicator is the most business oriented as it includes survey data from questions addressed to the business community in the different countries. Despite these differences, Archibugi and Coco (2005) underscore the convergence in the country rankings in the four classifications. Table 7 compare the results for the 47 countries that were common to the four classifications and for data from the late 1990s to the early 2000s.[21] This table does not include some countries with very substantial S&T capabilities, such as Taiwan, Switzerland and Denmark. It includes however a great diversity of economies, both more and

[21] The standard deviation of the rank mean in column 6 is one way to evaluate convergence across the classifications.

less developed than China. It thus allows to rapidly compare China's S&T capabilities with a broad range of countries. Rankings differ substantially across classifications for some countries, such as Japan, Korea or Norway. This may be partly due to very favorable or very severe judgments from survey data in the WEF classification. [22] In the case of China, the four classifications give quite close rankings and an average rank of 38 out of the 47 countries in the table. The RAND index is more favorable (33), which may be due to some data that are not included in other indicators (number of R&D institutions, internationally co-authored papers and number of scientists and engineers).

China's average ranking is quite modest and contrasts with the ranking on some of the indicators examined above. This may be due to the fact that the four classifications use per-capita indicators. We saw that Chinese S&T capabilities increase rapidly and the ranking of China may have substantially improved over the last couple of years. The last column on the right includes the results of an updated WEF classification. It shows that China's ranking had not changed; in the 2005-2006 classification, it is even lower.

According to the Technological Infrastructure Indicator (TII) computed by the Georgia Institute of Technology, the ranking of China has on the contrary substantially improved between 1999 and 2005 (Porter *et al.* 2006). Besides, according to that indicator, in 2005, China's performance is higher than that of a number of advanced countries. Such striking results call for at least two methodological remarks. First, Georgia Technological Institute computes two versions of its TII. The first one includes both hard data and survey data from a questionaire to experts and the second version only includes statistics. According to the version that includes expert opinions, the position of China is better (3rd instead of 7th in 2005 for the statistics only indicator). Second, TII includes a number of usual data on R&D input and output, but some are in total amounts rather than per capita. As discussed above, this introduces a strong biais in favor of China (as opposed to small R&D intensive countries like Israel or Switzerland).

This discussion suggests that despite impressive improvements, the scentific and technological capabilities of China are still modest. They seem actually consistent with China's level of economic and social development. Qualitative opinions from the business community or experts tend to consider that the S&T standing of China is much better than what the hard data reveals. This seems partly due to the rapid increase of some R&D inputs and outputs. It is also due to the export performance of China in some high tech sectors. The attractiveness of China for foreign R&D units also plays a role in the optimist perception of many experts. We have seen though that exports of high tech products involve only small local value added, and not much local R&D or technological value added. We also noticed that foreign R&D units have been largely pulled by local production and market access considerations. It is possible to say that "indices of technological prowess show a huge improvement of the technological capability of China" (Freeman 2005). However, the level of technological capability in China is comparable to that of other emerging countries. Brazil achieves a better average ranking and has moved up more rapidly in WEF ranking (table 7). Brazil enjoys higher standards of living than China, but India, which is poorer, is relatively close in the rankings and has come closer in the 2004-2005 WEF classification.

[22] Such opinions may change from one year to the other.

Table 7. Comparison of four classifications of technological capabilities of countries*

	Science and Technology Capacity Index RAND	**Technology Achievement Index UNDP**	**Indicator of Technological Capabilities ArtCo**	**Technology Index WEF**	**Comparison between the four classifications**			**TI WEF 2004-05**
					Rank mean	Standard deviation	Rank on the mean	
US	1	2	4	1	2.0	1.41	1	1
Finland	4	1	2	3	2.5	1.29	2	2
Sweden	3	3	1	5	3.0	1.63	3	3
Canada	2	9	5	2	4.5	3.32	4	10
Australia	8	10	8	4	7.5	2.52	5	12
Norway	10	12	6	6	8.5	3.00	6	7
Japan	5	4	7	19	8.8	6.95	7	4
UK	9	7	11	8	8.8	1.71	8	13
Netherlands	12	6	9	11	9.5	2.65	9	11
Germany	6	11	10	12	9.8	2.63	10	9
Korea	16	5	15	7	10.8	5.56	11	6
Israel	7	18	3	21	12.3	8.62	12	5
Belgium	13	14	13	10	12.5	1.73	13	24
New Zealand	17	15	12	9	13.3	3.50	14	18
Singapore	15	8	17	15	13.8	3.95	15	8
Austria	14	16	14	13	14.3	1.26	16	16
France	11	17	16	14	14.5	2.65	17	23
Ireland	18	13	18	23	18.0	4.08	18	26
Spain	21	19	20	22	20.5	1.29	19	15
Czech Rep.	23	21	24	16	21.0	3.56	20	14
Italy	20	20	19	26	21.3	3.20	21	34
Slovenia	19	23	21	25	22.0	2.58	22	19
Hungary	26	22	25	17	22.5	4.04	23	22
Slovakia	25	24	23	24	24.0	0.82	24	21
Portugal	24	26	27	20	24.3	3.10	25	17
Greece	22	25	22	30	24.8	3.77	26	38
Poland	27	28	26	28	27.3	0.96	27	31
Malaysia	38	29	33	18	29.5	8.50	28	20
Bulgaria	28	27	28	38	30.3	5.19	29	37
Argentina	29	21	29	36	31.3	3.30	30	36
Chile	30	34	30	33	31.8	2.06	31	25
Costa Rica	34	33	34	27	32.0	3.37	32	35
Romania	31	32	31	35	32.3	1.89	33	32
Mexico	36	30	35	29	32.5	3.51	34	33
South Africa	32	35	32	34	33.3	1.50	35	28
Thailand	41	36	37	31	36.3	4.11	36	30
Brazil	35	37	38	37	36.8	1.26	37	29
Philippines	42	38	39	32	37.8	4.19	38	38
China	**33**	**39**	**41**	**39**	**38.0**	**3.46**	**39**	**39**
Peru	40	41	36	42	39;8	2.63	40	42
Bolivia	39	40	42	45	41.5	2.65	41	46
Ecuador	44	42	40	46	43.0	2.58	42	45
Egypt	43	43	44	43	43.3	0.50	43	41
India	37	46	47	44	43.5	4.51	44	40
Sri Lanka	47	45	43	40	43.8	2.99	45	44
Indonesia	46	44	45	41	44.0	2.16	46	43
Nicaragua	45	47	46	47	46.3	0.96	47	47

* 47 countries common to the four classifications.
Background data for the four rakings (col. 2 to 4) are for the late 1990s and very early 2000s.
Source : Adapted from Archibugi and Coco (2004) and WEF (2004)

According to Gilboy (2004), China has developed a few centers of technological success, but the latter are poorly connected and integrated in the economy. He suggests that rather than thinking of China as yet another Asian technological and economic "giant," it may be more useful to regard it, like Brazil or India, as a "normal" emerging industrial power.

Conclusion

China very actively promotes investments in R&D. As a result, funding for R&D has been growing exponentially and China's R&D intensity has also increased rapidly over the last decade. More generally, China has been catching up with other dynamic Asian economies and the Triad economies on a score of indicators of R&D and innovation. China nevertheless remains low in overall rankings of scientific and technological capabilities. Based on their observation of the history of more advanced countries, Jian and Jefferson (2005) estimate that China has begun its technology takeoff. They remark that there is a tendency of the transition from low to high R&D intensity to be non-linear, with a take-off stage during which middlle income countries tend to experience a steep relationship between GDP per capita and R&D intensity. Jian and Jefferson (2005) give the example of a number of European countries, for which R&D intensity jumped from 1% of GDP to over 2% in a decade. In the most recent case, Korea made its technology take-off in 5 years, between 1983 and 1988. In the case of Japan however, it was much longer. Besides, the experience of Korea suggests that this intensification of R&D spending in the economy has to be accompanied by institutional changes for the country to nurture high tech local companies and substantially increase its contribution to world innovation (Kim 1997, Sachwald 2001). Numerous experts of innovation systems and development processes have also underscored the role of institutions and the business environment to promote research and innovation.

Denis Fred Simon (2005) considers that the reforms of the Chinese science and technology system over the past two decades are beginning to come to fruition. China could thus experience a take-off and become a major player in science and technology if not a technological superpower. Drawing on the information gathered in the paper, two sets of issues may be raised in this perspective. Firstly, a number of weaknesses may be underscored as roadblocks on the way towards China's science and technology take-off. Secondly, it is useful to come back on the integration of China's system of innovation in the global knowledge economy.

Obstacles to S&T upgrading

Over the last decade, increased R&D input, output and returns to R&D investment have seemed to increase harmoniously in China (Jiang and Jefferson 2005). Growing investment has been reflected in rapidly increasing scientific publications and patents, which suggests an efficient coupling between input and output. China's scientific paper publication outperforms its investment in basic research, which may be explained by abundant resources for R&D in universities and research institutes, that can be tapped for little extra funding (Seong *et al.* 2005). More generally, the abundance of human resources has played a crucial role in China's progress in both manufacturing and R&D location. We saw, however, that this abundance of human resources does not translate into high quality R&D output, whether it is measured in terms of paper citations or international patents. The limited capability of domestic firms to propose new products and services may be considered as a complementary indicator (Gilboy 2004, Seong *et al.* 2005) .

For China to become a technological power, rather than a location where sophisticated products are assembled by foreign affiliates, knowledge would need to diffuse more broadly into the local economy and indigenous firms would need to move up the technology ladder. Business investment in R&D has substantially increased in China, but industrial R&D remains the weak link in the national innovation system. Motohashi (2005) shows that Chinese firms have increased their interactions with the public research institutes and universities with a positive impact on their technological capabilities. However, most Chinese firms have not enough absorptive capacity to benefit from such research collaborations. They tend to focus on short term objectives and to struggle to realize exiguous margins at the lower reaches of global industrial production chains.

Technonationalism vs. Technoglobalism

China does not own the technology it operates and one major driver of its innovation policy has been to nurture domestic innovation so as to reduce its dependance on foreign technologies. Speaking at a national conference on innovation in January 2006, Premier Wen Jiabao noted that "independent innovation" was core to the country's development strategy over the next 15 years. One worry from China's foreign partners has been that this ambiton could generate technonationalist policies and promote the rise of a mercantilist economic superpower.

China has heavily invested in emerging scientific and technological fields where the domination of advanced countries may not be well established (Kang and Segal 2006). In sectors where Western companies dominate, China has tried to develop new standards for third generation cellphones, WiFi, authentification and privacy infrastructure and radio frequency in particular. The objective is to capture value from successful R&D through the building of a Chinese intellectual property protfolio and its incorporation into standards. This policy, has raised many worries among China's trade partners. Success has however been uneven and China has engaged in a more complex standards strategy, recognizing that narrow technonationalism is likely to be self-defeating (Suttmeier *et al.* 2006).

More generally, as China pushes toward developing its own technologies, the degree to which it continues to rely on knowledge from advanced countries is clear. Ongoing parnerships betweeen Chinese and foreign firms, the promotion of scientists trained abroad and the welcome that multinational R&D facilities receive suggest that the pursuit of technonationalist objectives in a globalized world is neither straightforward nor easy. The strong integration of China in the global economy represents a divergence from the typical Asian success story. China's science and technology take-off seems to start at a lower level of standard-of-living than that of Korea and Taiwan, which may be partly due to its tighter integration in the global knowledge-economy.

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