Science and Technology in China

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October 29, 2004

Prepared for Conference 2:
"China's Economic Transition: Origins, Mechanisms, and Consequences"

Pittsburgh, November 5-7, 2004

PRELIMINARY DRAFT: comments are welcome

1. Introduction

Economists agree that the long-term growth of living standards depends on the capacity of an economy to sustain technological progress, whether by adopting technologies from abroad or through its own technological innovations. The pace and sustainability of the growth of living standards in China will likewise depend on its ability to absorb and innovative new technologies and the future trajectory of this capacity. The purpose of this paper is to present an overview of China's science and technology capabilities and the economic, institutional, and policy context that together determine the range and growth of these capabilities.

A critical aspect of China's drive to achieve technological parity with the advanced OECD economies is its ability to sustain its transition from a state-dominated economy to a market driven system in which the enterprise sector, independent research institutes, and a vibrant research university sector effectively pursue their science and technology objectives. The quality of the outcomes of such a system will depend on the ability of China's legal, institutional, and policy framework to create a set of incentives that effectively balances the distribution of private and social returns to S&T activity. That is, China's S&T system needs at once to allow for the enterprise sector to expropriate the returns to R&D to motivate the creation of new knowledge while also allowing for diffusion and spillovers needed to maintain a competitive, dynamic economy.[1] Against these measures, China has made dramatic advances relative to 25 years ago but continues to face substantial obstacles in its quest to move to toward the world technology frontier.

This essay is organized in eight sections. Section 2 undertakes a cross-country and historical comparison of China's S&T activity levels. Based on the finding in Section 2 of the rising intensification of S&T activity in China, we investigate in Section 3 the sources of China's rapidly rising levels of S&T activity. Section 4 specifically focuses on the contribution of the foreign sector to China's technological advance, addressing the issue of the relative roles of the domestic and foreign sectors. Section 5 examines the incentive framework, including the policies and programs of the Chinese government in promoting S&T. Section 6 reviews the available literature to formulate an overall evaluation of the impact of S&T activity on the Chinese economy, including assessments of the sectors that have been most affected by China's S&T intensification. In Section 7, we speculate on the sustainability of the growth of China's S&T activity. Section 8 presents a set of conclusion and discussion points that follow from the analysis presented in the previous sections.

[1] See Easterly, Ch. 8 on the role of technology "matches" and "leaks" for technological progress.

2. How does China's S&T activity compare internationally?

In order to assess China's progress in the arena of science and technology, we first attempt to compare China's level of S&T activity with the levels of other countries – both OECD countries and other emerging industrial economies. The measures that we principally focus on are four measures on innovation input – the ratio of R&D/GDP, the proportion of S&T workers in the total population, the proportion of R&D dedicated to basic research, and the share of R&D spending financed by the enterprise sector. We also focus on three measures of S&T outputs. These are patents that have been granted to the residents of China compared with other nations and two measures of the relative technological sophistication of China's exports. The comparisons are shown in Table 1. We examine these below:

R&D intensity. The data in Table 1 show that China's R&D intensity sharply accelerated during 1995 to 2000 and continued to rise into the current decade. The pattern is similar to that of Brazil, whose R&D intensity also rose sharply during the past decade. During the early 2000s, China and Brazil's R&D intensity lay in the range of 1.0 to 1.3 percent, while those of most OECD economies and Taiwan lay in the range of two to three percent.

For China, this level of R&D intensity is high given its living standards. Among the 88 countries reported in the *UNDP Human Development Report, 2001*, we see that China is the only low or low-middle income country whose level of R&D intensity has risen beyond one percent.[2] While Brazil exhibits a similar pattern, its level of per (exchange rate adjusted) capita income is approximately three times that of China. India's level of R&D intensity remained relatively stable during the decade of the 1990s. Hovering in the range of 0.8 percent in 1990, 1996 and 1999, it does not exhibit the acceleration of China's R&D intensity.

R&D orientation. Although the intensity of R&D is rising sharply, so that its total R&D spending is approaching the levels of the mid-sized OECD economies, including Italy, Canada, and Australia, the basic research component of these funds is substantially less than that of their OECD counterparts. Table 1 shows the share of basic research in total R&D in China – just five percent – stands between a quarter and a half of the proportions reported by the U.S., Japan, and Korea.

We also compare the role of the enterprise sector in each of our countries. Table 1 shows that at 57.6 percent, China's enterprise sector funds a somewhat smaller proportion of total R&D spending than do the enterprise sectors in the U.S., Japan, and Korea. On the other hand, the proportion of total R&D spending funded by the enterprises sectors in the U.K. (46.2%), France (52.5%), Italy (44.0%), and Canada (40.0%), is less than the funding share of China's enterprise sector.

[2] In the data reported in UNDP (2001), China's level is just 0.7 percent. Comparative country data in NBS (2003), however, indicates, however, that by 2002 the R&D intensities of other low-middle income countries had not exceeded one percent.

Scientists and engineers. Table 1 also shows the relative intensity of scientists and engineers per 10,000 population. In China, at just 10 this proportion substantially lags behind the other countries shown in Table 1. The intensity of scientists and engineers in Turkey is comparable to China while the proportions for Italy (28), Austria (48), the U.K. (55), and Canada (58) lie between the proportions for China and the U.S. and Japan. Nonetheless, because of its large population, the sheer number of scientists and engineers in China exceeds the numbers for all countries except the U.S. Moreover, China is producing new scientists and engineers at a substantially higher rate than any of the OECD countries.

Patenting. The first R&D output measure that we use is the number of approved patents registered with the U.S. patent office by the residents of different countries. The number of such patents registered by Chinese residents is among the lowest of the countries shown on the list in Table 1. This measure of innovativeness, a measure of the rents that producers can capture from their R&D spending, appears to lag substantially behind other measures of S&T intensity, including R&D spending and the number of scientists and engineers. Whereas China has more scientists and engineers than all countries but the U.S., the relative productivity of these technical personnel in producing patentable innovations is low.

Export quality. Data compiled by the World Bank and reported in Table 1 shows a steady rise in the proportion of high-tech exports to approximately 23 percent in 2003. The data for other countries, middle low-income countries like China as well as upper middle income and upper income countries shows that for broad groupings of countries the share of high tech exports in total manufactured exports rises monotonically with income per capita; nevertheless, the specific country data show substantial variation within income groupings. Nevertheless, Table 1 shows that China compares favorably with India, Brazil, and Japan.

Of greater significance, is the rapid growth of the high-tech composition of China's exports, rising from about six percent in 1990 to 23 percent in 2002. Moreover, while in 1995, foreign-invested enterprises accounted for as much as 80 percent of China's overall exports in such capital and technology-intensive industries as electronics and electrical appliance, by the year 2000, this number had fallen to about 50 percent.[3]

Shott (2004) assesses the relative sophistication of China's exports in terms of the degree of overlap between Chinese exports to the U.S. and those originating from the OECD countries other than the U.S. Table 1 shows both a rapid rate in the measure of overlap, having grown over the past 30 years, from just nine percent in 1972 to 75 percent in 2001. Moreover, the extent of China's OECD overlap exceeds that of the other Asian economies and Latin America.

[3] Walsh (2003), pp. 4,5 and Huang, 2003.

Overall, Table 1 shows that China's S&T intensity is rising rapidly.[4] This rising S&T intensity, however, has not yet propelled China into the upper ranks of innovating countries as measured by basic research new patent production. This relative paucity of basic R&D combined with the paucity of high-quality patents suggests that the vast proportion of China's S&T resources are focusing on technology transfer and process innovation. This focus, in turn, seems to be enabling Chinese producers to imitate the quality and efficient production of an increasingly large proportion of goods that are found on world export markets.

3. What is driving the intensification of R&D in China?

The Human Development Report, 2001, which focused on the role of technology in human development reveals several patterns. The first is that all of the world's richest 20 countries registered rates of R&D intensity that exceeded one percent. The seven largest of these high-income countries registered R&D intensities that equaled or exceeded two percent. Furthermore, with the exception of but a few countries, all of the countries that did not qualify as "high income" by World Bank standards reported ratios of R&D spending to GDP below one percent.

The largest and richest seven economies share another feature: they all experienced science and technology (S&T) takeoffs. S&T takeoff is defined here as an abrupt increase in a country's ratio of research and development (R&D) spending to GDP from less than one percent to more than two percent. For these large, high-income economies, this remarkable acceleration in the ratio of R&D spending to GDP occurred on average within the span of a single decade.[5]

From 0.6 percent in 1996, China's statistics show its R&D intensity accelerating rapidly to 1.3 percent in 2003. At 1.3 percent, China's R&D intensity is one-half that of the U.S. and substantially greater than what should be expected given the country's level of per capita income.[6] This acceleration raises two questions: What is driving China's R&D intensification? Has China begun its S&T takeoff? This section focuses on the first of these questions. We wait until the conclusion to speculate on the second.

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[4] Some observers question the quality of China's R&D data, such as that shown in Table 1. The provision of tax subsidies for R&D spending, for example, may provide an incentive to Chinese firms to over-report their R&D spending. However, at least until recently, the rates of taxation levied on R&D-related investments have been 33% for domestic firms and just 17% for foreign firms (Walsh, 2003, p. 29), thus providing a countervailing incentive for domestic firms to underreport in relation to foreign firms. It should also be noted that the U.S. and many European countries, like China, maintain incentives for R&D.

[5] A review of Table A2.2 in the UNDP, 2001, shows that the U.S., Japan, German, the U.K, France, Italy, and S. Korea, all with populations in excess of 47 million, had ratios ≥ 2.0. See Gao (1997) for a comparative discussion of national S&T takeoffs. While S. Korea completed the transition within a mere four years and Japan required 18 years, the U.S, the U.K., Germany, and France all completed theirs within one or two years of the mean duration of 10 years.

[6] In 2003, the World Bank defined the category of "lower-middle income" countries to include those countries with per capita incomes in the range of $745 to $2,975. With a reported level of per capita income of $890 in 2002, China lies toward the bottom of this range.

We identify several leading factors that are contributing to China's growing innovative intensity. The principal source of China's growing R&D intensity is the shift in consumption and production patterns within China's economy as incomes rise. Several distinctive features that distinguish China from most lower middle-income countries may accelerate this shift.

In addition to focusing on changing consumption and income patterns, which generally relate to China's status as a developing economy, we focus on the underlying shift in the structure and composition of its innovation resources, as it moves from a planned to a market economy. In particular, the shift in S&T funding sources away from government and the expanding and increasingly independent roles of the enterprise sector and research institutes warrant attention. During the early 2000s, China became the largest recipient of foreign direct investment. In the following section, we focus on the role of the foreign sector in motivating China's growing S&T intensification.

Shifting consumption and production patterns.

As living standards rise, the composition of goods and services shifts from those that are low in their technology content to goods and services that are more technologically intensive. Automobiles substitute for bicycles; consumer electronics become ubiquitous, medical services and the equipment that supports them become more sophisticated. This pattern of technology intensification that accompanies rising living standards parallels Engel's Law. As incomes rise, not only is the income elasticity of demand for non-agricultural goods greater than one, but also goods with low-technology content (e.g. bicycles, handicrafts, rudimentary medical care) are inferior goods. The implication is that the income elasticity of demand for high-technology goods is high.

Within China, the electronics and telecommunications industry is illustrative of China's emerging high-tech industries. Table 2 features three of these industries. The Table shows, for example, that within our LME data set, during the latter half of the 1990s, the ratio of R&D spending to value added in the electronic and telecommunication sectors accelerated by 250 percent to reach nearly 7.5 percent. The overall impact on Chinese industry of the growth of R&D intensity in this sector was magnified by the fact that its market share in total industry sales doubled over this period. Table 2 shows that this association between rising R&D intensity and growing market share is also exhibited by the other China's equipment and machinery industry and the instrumentation sector.

China exhibits several features that make this shift to technologically sophisticated industries particularly abrupt. We emphasize three of these.

High rates of literacy. At 16.5 percent, China's adult illiteracy rate in 1999 was approximately twice that of Singapore, similar to those of Brazil (15.1%) and Turkey (15.4%) with substantially higher incomes, and well below that of India (43.5%). These comparatively high rates of literacy in China are likely to enhance the demand for and utilization rate of technology intensive goods and services, such as telecommunications services, computing, and medical services.

A paucity of prior infrastructure. The paucity of installed infrastructure for earlier generation technologies, such as land telephone lines, earlier production technologies, including earlier vintages of automobile assembly lines, and earlier computing technologies, both hardware and software, open the door for the rapid dissemination and adoption of the latest technologies. In certain key sectors, such as telecommunications and automobiles, for example, we observe a substantial degree of technology leapfrogging.

Market size. While other developing countries may import technologically sophisticated electronic and telecommunications equipment and other high-tech goods, including electrical machinery, instrumentation, and automobiles, multinationals are clamoring to set up production for these R&D intensive industries in close proximity to China's burgeoning consumer markets. This phenomenon of the commercial desire to set up production in close proximity to large markets may explain why S&T takeoff has not occurred in certain smaller OECD countries (e.g. Norway, Australia, Belgium, Austrialia, and New Zealand) while it has occurred in all of the largest OECD economies.[7]

The pattern of shift toward the consumption of goods with increasing technology content is part of a virtuous circle of growth and technological development in all countries that enjoy sustained growth. But the three factors cited above – high literacy rates, the relative absence of earlier vintage infrastructures, and market size – are likely to amplify the pace and breadth of the transformation.

Below, we briefly examine the respective contributions of government, the enterprise sector, the research institutes, and the foreign sector in driving this intensification of R&D.

The shifting locus of R&D activity.

This shift toward the consumption and production of goods and services with comparatively high technology content is likely to result in growing S&T roles for the business sector and research institutes. In the case of China, however, the country is also moving away from central planning in which the government was the primary source of S&T resources and the majority of the enterprise sector and complex of research institutes were under the supervision of the government. This shift is rapidly altering the loci of R&D activity and the incentive structure of China's innovation system. We describe these shifts below; in Section 4, we focus on the contribution of the foreign sector; in Section 5, we examine the implication of the changes, for the incentive to innovate.

(i) Government's role. With China still transitioning from its central planning legacy, China's government might be anticipated to play an active role in financing and

[7] The desire to serve large and fast growing consumer markets creates a premium for the establishment of production centers that can benefit from learning-by-doing and learning-by-using in close proximity to burgeoning demand.

directing R&D. In 1991, government sources in China accounted for nearly 30 percent of science and technology funding, a category that closely tracks with R&D funding. The firm sector, which in market economies is the primary source of R&D financing, accounted for just 28 percent of S&T funding. By 2002, however, these figures had significantly changed as government's financing share fell to one-quarter while the share of the enterprise sector rose to over 57 percent, a figure that lies within the range of the largest OECD economies. In 2002, the enterprise sector performed 61 percent of all R&D expenditure, followed by the independent research sector, which accounted for 27 percent.[8] In 2000, government funding accounted for just 6.8 percent of total R&D expenditure; most government support was, and continues to be, directed through the research institutes administered by the central government. (R&D Census, 2002, p. 7)

In China, the central government also stimulates R&D though the provision of grants and tax incentives to the enterprise sector. China's National Bureau of Statistics (NBS) conducts an annual census of its approximately 22,000 large and medium size enterprises (LMEs). These enterprises, which account for three quarters of China's industrial R&D spending and over one half of its industrial sales, receive the majority of these R&D grants and tax subsidies. Over the period 1995 to 2001, R&D grants as a proportion of R&D spending fell by more than half while the proportion of tax subsidies fell by somewhat more than one-third. These declines indicate that government funding has not driven the abrupt increase in China's R&D spending. To the contrary, these changes in funding shares over the past decade show that the surge in China's R&D intensity has been associated with the rapid growth in enterprise-financed R&D, as China has moved toward a market economy.

(ii) The enterprise sector. Table 3 shows the adoption of R&D operations within the industrial LME sector and the intensification of R&D operations among existing R&D performers. We see during 1995 to 2001 increasing rates of adoption of R&D activity by China's industrial LMEs. During this period, R&D performers rose from 19.7 percent to 28.7 percent, a rise of nearly one-half. Over the same period, firms that had been R&D performers in 1995 intensified their R&D operations. The number of high performing LMEs with R&D sales ratios in excess of three percent grew from 544 to 1,581. All but 275 of these were domestically owned LMEs. As established R&D performers gain experience and access to foreign technology, rising returns to R&D motivate firms to move more resources into their R&D operations thereby causing industrial R&D intensity to rise.[9]

(iii) The research institutes (Rips). For 2002, China reports on the activities of 4,347 research institutes. Of these 744 are directly supervised by the central government, including the 98 institutes that comprise the Chinese Academy of Sciences. Together

[8] NBS (2003), p. 7.

[9] Measured in terms of productivity gains, cost reductions, or increased profitability, research on returns to R&D consistently show substantial returns to Chinese-based R&D. See Hu and Jefferson (2004a), Jefferson, Bai, Guan, and Yu (2004), Jefferson and Zhong (2004), Fisher-Vanden and Jefferson (2004), and Hu, Jefferson, and Qian (2004).

these institutes account for 70.3 billion Yuan in S&T spending, which represented 24 percent of China's S&T funding. Among these funds, 71 percent originated from government sources, accounting for nearly two-thirds (64%) of government S&T funding. However, 82 percent of that spending was dedicated to the Rips operating under the control of the central government, leaving government funding accounting for 30 percent of the funding sources for RIs operating outside the purview of the central government. That is, more than one-half of the Chinese government's S&T finding is channeled to the 744 RIs that it directly supervises. (NBS-MOST, pp. 6, 30).

With 11.6 percent of the R&D budgets of these RIs dedicated to basic research – compared with 5 percent for total R&D spending – we see that China's research institutes are the locus of basic research in China's S&T system, particularly those that are directly under the control of the central government that in turn account for 96 percent of the basic research in the RI sector. (NBS-MOST, 2003, p. 31).

Beginning in the late 1990s, China government initiated a substantial restructuring of its research institutes involving efforts to place them on an independent financial footing. In 2003, it reported that the restructuring of 946 of the RIs had been completed. Among these 511 had been converted to S&T enterprises (*kejixing chiye*) and 340 had been incorporated into enterprise groups. Seven had been incorporated into universities. The dominant form of restructuring outcome – approximately 90 percent – therefore, has been for research institutes that were previously managed by the state to become either become or be incorporated into freestanding enterprises.

Leading regions. Not surprisingly, China's eastern provinces dominate the country's R&D spending. Furthermore, within the eastern region, the cities of Beijing and Shanghai and Guangdong and Jiangsu provinces account for two-thirds of the region's R&D spending. Table 4 shows that while covering less than 15 percent of China's population, these four sub-jurisdictions account for nearly one-half of the nation's total R&D spending.

Wei (2002) investigates technology disparities across China's 30 provinces. By weighting data from 20 R&D input and output measure (e.g. R&D intensity, LME R&D spending and personnel, new product development, patenting) Wei develops a ranking order, consisting of Beijing, Shanghai, Tianjin, Guangzhou, and Jiangsu at the top. This ranking suggests an ordering of technological capabilities that closely parallels ranks of total R&D expenditure. While these results confirm the dominance of S&T activity in China's eastern provinces, Wei's composite ranking of the eastern region (0.394), central region (0.265), and western region (0.299) suggests that the underlying disparities may

not be a striking as suggested by the fact that just four independent municipalities and provinces account for nearly half of China's total R&D.[10]

Other studies suggest still larger disparities than those found by Wei . As part of a World Bank study on innovation in East Asian cities, Jefferson and Zhong (2004) compares the R&D capabilities of five Chinese cities – Beijing, Chengdu, Guangzhou, Shanghai, and Tianjin – and Seoul, South Korea. The index of R&D capabilities shown in Table 5, based on surveys of 300 firms in each of the six cities, summarizes differences reported by the firms in each city with respect to openness, human capital resources, R&D networking, and institutional quality across the six metropolitan areas. The index shows Seoul as the city with the greatest overall R&D capabilities, followed by Shanghai, Guangzhou, Beijing, Chengdu, and Tianjin. The estimates show a robust relationship between the metropolitan indexes of R&D capabilities and metropolitan wide returns to R&D. Perhaps the finding of greatest interest, is the relatively large margin the authors find in Chinese cities between the cost of R&D personnel and the returns to R&D personnel compared with the relatively small spread for Seoul. This result suggest substantially higher net returns to foreign firms seeking to outsource portions of their R&D operations from choosing a Chinese venue compared with Seoul.

Using the NBS's industrial LME dataset, Jefferson and Xu (2002) also find evidence that the technological disparity between the coastal provinces and the interior provinces is not only large – in favor of the coast – it has also been growing to the advantage of the coastal region. Table 6 shows that during the latter half of the 1990s, along virtually every dimensions of technological progress, i.e. R&D intensity, firm productivity, profitability, patents, new product sales, and the intensity of foreign direct investment (FDI), China's coastal LMEs continued to expand their dominance over their counterparts in China's interior.

4. Does the foreign sector account for China's technological advance?

Much of the literature on China's S&T system divides over the issue of the respective roles of the domestic and foreign sectors in driving China's technological advance. Analyses that have focused on the question of the role of the foreign sector in China's S&T system include Kathleen Walsh (2003), "Foreign High-Tech R&D in China," and George Gilboy (2004) "The Myth Behind China's Miracle." Gilboy (2004) takes a decidedly more skeptical view of the capabilities of China's domestic S&T capabilities, characterizing China's domestically owned firms as hampered by:

> …an "industrial strategic culture" that encourages them to seek short-term profits…(and) forego investment in long-term technology development and

[10] The dominance of the western region over the central region results for the assignment of Sichuan province (consisting of two observations – Chongqing and the balance of the province, which includes Chengdu) to the western region rather than the eastern region. In Pan's ranking Chongqing and Sichuan are ranked 8 and 9 respectively.

> diffusion….Most Chinese industrial firms…have not increased their commitment to developing new technologies….R&D expenditure as a percentage of value added at China's industrial firms is only about one percent, seven times less than the average in countries of the OECD. (p. 43).

To test this idea that firms with FDI participation dominate R&D operations in China, we turn to our data set for China's industrial LMEs. According to the LME census data, in 2001 total R&D expenditure within China's domestic industrial LME sector was approximately four times that of the foreign funded enterprise (FFE) sector, which we define as including both foreign firms and overseas investment from Hong Kong, Macao, and Taiwan (HMT). That is, in 2001 domestic firms accounted for 78 cents of every R&D dollar spent by the enterprise sector.[11] Moreover, as shown in Table 7, in 2001, while the ratio of R&D to value added in China's domestic LMEs had reached 3.3, for the foreign firms it stood at just 2.6. This finding is broadly consistent with a recent OECD report that states, "…foreign firms that invest in China appear to have engaged in only limited levels of R&D activity and their role in the innovation process seems even more limited. (OECD, 2002, p. 267)

Again according to Gilboy, "Chinese firms are taking few effective steps to absorb the technology they import and diffuse it throughout the local economy, making it unlikely they will rapidly emerge as global industrial competitors." (p. 38) Once again, the LME data set shows a different picture. In 2001, 1,460 LMEs, over 80 percent domestically owned, recorded purchases of imported technology. Furthermore, the foreign invested enterprises (FIEs) purchased virtually nothing in China's domestic technology markets. In conclusion, except for their parent companies from whom they transfer technology, the FIEs are substantially less connected with local technology markets than their domestic counterparts. The key conclusion of this section is that while FIEs are contributing to China's openness and rapid export growth, they do not constitute the leading edge with respect to China's rising R&D intensity – at least not directly.

In the previous section, we saw that FIEs are not directly and substantially contributing to China's rising R&D intensity. But the foreign sector does play a key role in motivating rising R&D intensity through at least two indirect channels. First, my research colleague, Albert Hu, and I (2004) find that the R&D intensity of domestic firms is rising most quickly in industries with high FDI participation.[12] The competition and the proliferation of product variety associated with high industry FDI participation create pressures for domestic firms in these FDI rich industries to mount extensive and effective R&D programs to hold their own against foreign competition.

A second channel though which the foreign sector contributes to rising R&D intensity is through the access to foreign technology it provides for domestic firms.

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[11] Accounting for the fact that in 2001, 61 percent of China's foreign funded enterprises were domestically owned, we can reapportion a proportional share of the FFE research and development spending to the domestic side of the ledger. The domestic share of China's LME industrial R&D spending then rises to 91 cents on the dollar.

[12] Hu and Jefferson, (2004b).

Chinese firms are finding that in-house R&D is needed to access and absorb effectively these technologies from abroad. Research shows that the firms that purchase imported technology invariably also support in-house R&D operations. In-house R&D shares strong complementarities with technology imports, enabling domestic firms to capture higher returns to their own R&D spending.[13] Our research also finds that domestic firms that combine in-house R&D with imported technology are more likely to be active exporters.[14] By creating incentives for domestic firms to perform R&D while also enhancing the impact of R&D by combining it with foreign technology transfer, the China's fast growing foreign sector is supporting the growing capabilities of Chinese owned companies to compete on world markets.

One component of the foreign sector does seem to be contributing substantially to China's R&D effort – that is majority-owned U.S. affiliates, which in 2000 numbered 458. During 1997 to 2000, the R&D intensity of these firms rose from 1.1 percent in 1997 to 9.2 percent in 2000. Such affiliates with major R&D activities or facilities include Dupont, Ford, G.E., General Motors, IBM, Intel, Lucent Technologies, Microsoft, and Motorola. (Moris, 2004). The level of R&D intensity of these U.S. affiliates of 9.2 percent substantially exceeds 3.3 percent level of R&D intensity for aggregate U.S. affiliates in all host countries, a measure of the relative draw of China and the government's "technology for markets" policy. In addition, a number of these foreign affiliates with substantial R&D operations have established R&D allocates with Chinese counterparts. According to the Thomas Financial Joint Ventures Alliances database, U.S. and Chinese-owned companies and other organizations formed 105 new business alliances with a large R&D component from 1990 to 2001, substantially more than the 78 alliances formed with Japanese, German, British, Singapore, and Canadian companies during the same period. (Moris, p. 3).

Summarizing, in trying to single out the domestic or foreign sector as the key driver of China's technological advance, much of the literature takes a static view and regards the foreign sector and the domestic sector as disjoint. The three areas in which we find a substantial role for the foreign sector, suggests that the impact of FDI and FDI-related R&D activity operates through interactive channels: the industries that are most rich in FDI motivate increasing in-house R&D by domestic firms, which account for over three quarters of R&D spending, (ii) in-house R&D is an important precondition for domestic firms to successfully use foreign technologies, and (iii) joint ventures or R&D alliances are the dominant channel through which the R&D activities of the affiliates of U.S. and other OECD countries enter China. The foreign sector does play a critical role in motivating R&D activity in China, but this is largely achieved through its interaction with the R&D operations of domestic entities. Most generally, through these interactions, which raise the efficiency and returns on R&D investment by Chinese firms, we see a rapid pace of R&D intensification in the domestic sector.

[13] Hu, Jefferson, and Qian (2004a) show this result within the context of a production function. Fisher Vanden and Jefferson find this result using a cost function approach.
[14] Fisher-Vanden and Jefferson (2004).

5. What has been the role of incentives, including government policies and programs, in supporting S&T?

China's economic reforms have transformed the country's institutions that govern the incentive to innovate. Under China's pre-reform innovation system, state patronage shaped the allocation of innovation resources. In lieu of private pecuniary incentives, the Government employed official recognition and professional prestige and advancement to motivate research focus in certain limited areas. China's rapid progress in nuclear technology, space technology, and genetic engineering in the 1960s and 1970s testifies to the partial success of this system. Such a system was effective in supporting basic research, where albeit the private returns were low, the social returns and hence the attention and accolades of the Government were high. However such a system was ill defined to calibrate the complex incentive structure required for a broad-based system of commercial innovation that could effectively respond to the needs of the producer and consumer sectors that lay outside the immediate realm of the government's S&T priorities.

Enterprise reform and ownership restructuring has reestablished the profit motive and competition interplay to the innovation process. Enactment of the patent law in 1984 and the copyright law in 1990 signified the introduction of market-based incentives to China's national innovation system. A hybrid system has now emerged that consists of both state-led S&T initiatives and market-based institutions. The role of state patronage has largely been restructured to complement the market based incentive structure. In the discussion in Section 2, evidence of this restructuring appeared in the growth of the role of independent enterprises and research institutes in funding and performing R&D, the reduction in the role of government R&D grants and shift in emphasis to tax incentives, and the growing role of the foreign sector in motivating China's rising R&D intensity.

In the rest of this section, we investigate how the innovation incentive structure has changed by examining the changing roles of the state and market in allocating innovation resources, the effectiveness of patents in encouraging innovation, the design and consequence of various government S&T initiatives, and how the roles of the state and the market intertwine in the development of China's fast growing semiconductor industry.

The changing roles of the state and the market in technological innovation

Figure 1 below illustrates and expands upon the widely observed pattern of a shift in funding of S&T activity from the government to the firm sector. It shows not only the rising share of the enterprise sector in funding S&T, Figure 1 also shows the small and declining share of government-financed S&T in the important industrial LME sector, which accounts for nearly 42 percent of China's total S&T spending. While the government's share of S&T funding in the LME sector has fallen to just four percent, the enterprise share in 2002 rose to over 84 percent. The erosion of the industrial LME and government funding shares in total S&T spending suggest that S&T financing is shifting toward smaller enterprises, most of which are non-state enterprises, and independent

research institutes. The continuing restructuring of the research institute sector, described in Section 2, entailing its closer alignment with enterprise sector and its increasing reliance on its self-finance is also strengthening the incentive for commercial innovation.

New institutions: the case of the patent system. China's National People's Congress passed China's first patent law in 1984. The substantial revision of the patent law in 1992 expanded in general the scope of patent protection. The impact of stronger patent protection is clearly reflected in the annual patent grants plotted in Figure 2. The number of patents granted rose sharply in 1993. The temporary fall back in 1994 was followed by persistent and rapid growth of patents, particularly in the last five years, from 1997 to 2002 during which total patent grants increased at an average annual rate of 21 percent. Over the same period, the full-time equivalent of R&D personnel had increased at an annual rate of 4.4 percent, suggesting the reorientation and/or greater efficiency of China's R&D personnel toward novel innovation.

Figure 2 also shows that the surge in patenting is driven by "utility" and "design" patents, which represent incremental innovations and receive far weaker legal protection than that afforded by "invention" patents[15]. Absent an unlikely jump in innovation productivity, the evidence presented here accords well with the hypothesis that an increasingly effective patent system has substantially magnified the incentive to seek intellectual property protection.

The contrasting performance of domestic and foreign inventors exhibited in Figure 3 further corroborates the hypothesis of an increasingly robust patent system. Despite being dwarfed by domestic inventors in total patent grants, foreign inventors have taken out more invention patents than their domestic counterparts. Foreign invention patents' dramatic jump of seven fold from 1997 to 2002 is synchronized with the surge in domestic and overall patenting.

Government policies and the support of S&T. The transition from a system dominated by state patronage to one that gives a growing role to market driven institutions can potentially exacerbate market failure in areas of research where spillovers and externalities abound. Figure 4 shows that most of the increase in R&D personnel in the late 1990s has been driven by R&D personnel working on experimental development. The share of experimental development in total R&D also increased largely at the expense of applied research. The support for basic research has largely remained unchanged. This is partly due to the support that the Chinese government has provided through various science and technology development programs.

China's government supports two distinct types of programs: those that focus on supporting basic and frontier research and those with a primary objective to promote the diffusion of applied technologies. Table 8 summarizes the key features of the main

[15] Another indication of the low invention content of Chinese patents is the sharp contrast between invention patents granted to Chinese inventors in China and in the US shown in Table 1. Clearly the economic value of many Chinese patents seeking protection in the US is not large enough to compensate for the costs involved in obtaining a US patent.

programs. These include the "*Climbing up*" Program (***Pandeng***), the "*863*" Program (***Baliusan***), the "*Key Projects*" Program (***Gongguan***), the "*Torch*" Program (***Huoju***), the "*Spark*" Program (***Xinghuo***), and the "*Dissemination*" Program (***Tuiguang***), and the establishment of the "National Natural Science Foundation".

The first two programs – *Climbing and 863* – and the National Natural Science Foundation focus on supporting basic research or applied research of fundamental scientific significance. The objective of these programs is to narrow expeditiously the gap between China and the world technology frontier. As Table 9 shows, these programs are largely funded by the state and mostly performed by universities and research institutes. We are not aware in the public domain of any systematic studies that evaluate the effectiveness of these programs. Indirect and anecdotal evidence suggests that they have been productive. For example, in 2002 these programs together generated 408 invention patents, or 7 percent of all the invention patents granted to domestic inventors in China. The number of papers published by Chinese scientists in journals included in the Science Citation Index had increased from 5,408 in 1991 to 35,685 in 2001 moving China's rank in the world up from 15 to 8 (China Statistical Yearbook on Science and Technology 2003).

The latter four programs - the *Key Projects, Torch, Spark, and Dissemination programs* - deal mostly with the "D" or the development and diffusion stage of innovation. The Key Projects program and the Dissemination program are both top-down programs with the government acting as an agent between enterprises and research institutes and universities. The *Torch* and *Spark* Programs differ from the others in that they combine the "push" of direct government funding with the "pull" of market demand. For example, an important part of the *Torch Program* is the establishment of nation-wide science and technology parks to encourage the formation of high-technology start-ups. Instead of grants, government support is limited to preferential tax treatment within the park. Perhaps in part to compensate for risk taking by the enterprises, the government has allowed for a greater role of non-state ownership in these parks, which increases the private returns the entrepreneurs can expect to reap from their innovations. In a similar spirit, the *Spark Program* is intended to reduce barriers to technology diffusion in rural China by setting up over 500 technology "demonstration stations" across the country to educate and train farmers and rural entrepreneurs. But it is the latter that decide which technologies they adopt. The majority of the funding comes from self-raised funds and bank lending (Yuan et al 1992).

Both the Torch and the Spark programs have been successful. Walcott (2003) provides rich institutional details of China's science and technology parks established under the Torch program. Hu (2004) shows that these technology parks have been growing much faster than the cities that host them. He finds that their superior performance may have been driven more by policy incentives than by agglomeration or localization externalities. In a systematic evaluation of the Spark program, Du and Xu (1997) documented the multi-dimensional success of the program. For example, they reported that in 1995 township and village enterprises included under the Spark program

had an average profit rate of 7.83 percent, much higher than the national average of 3.09 percent. Furthermore, the TVEs set up under the Spark program had generated on average 139 new jobs. Although program evaluation is a difficult task, the Spark program did seem to have generated measurable economic benefit[16].

Industry policy and S&T policy in China's semiconductor industry: a chance to leapfrog?

The semiconductor industry has always been one of the pillar industries that the Chinese government has targeted for rapid development through its industrial and S&T policies. China's first science and technology plan, formulated in 1956, selected electronics technology, including semiconductors, as one of the 12 targeted areas for intensive government support (Yuan et al 1992). Chinese scientists' development of silicon digital integrated circuit in 1965 – seven years after Robert Noyce and Jack Kilby invented the integrated circuit – put China within reasonable reach of US leadership in semiconductor technology (CIER 1991). However, the disruption caused by the Cultural Revolution and the parallel explosive growth of the semiconductor technology left China far behind when it again contemplating modernizing its technologies in the early 1980s. In China's second major science and technology planning exercise in 1978, electronic computing was again selected as one of the eight major target areas for state support (Yuan et al).

A most remarkable example of technology catching up is the rise of the East Asian semiconductor industry led by Korea and Taiwan (Matthews and Cho, 2000). From 1984 to 2003 the Asia Pacific's share in world semiconductor production, consisting largely of Taiwanese and Korean firms, has increased from 6 to 39 percent. During this period, US and Japanese shares have declined from 47 and 31 percent to 19 and 23 percent respectively[17]. Korea is now the world leader in DRAM manufacturing, whereas Taiwan hosts the world's largest semiconductor foundry plants. Will China be the next to leapfrog to the world's semiconductor technology frontier?

Despite the rudimentary state of its technology in at the beginning of the reform period and the controls that the US and other countries have imposed on the export of certain semiconductor manufacturing equipment and materials,[18] the Chinese semiconductor industry has mounted a successful effort to close the gap with the world technology frontier. Figure 5 reproduces numbers reported by the GAO (2002) that contrast the technology gap between China and the US in semiconductor fabrication. China's modern semiconductor industry began in 1986 with the purchase from the U.S. of a second-hand 5 μm technology that represented the technological level in the U.S. and

[16] It is unclear that the study takes into account the non-randomness of participation in the Spark program. So the evidence presented is only suggestive.
[17] See www.sia-online.org.
[18] The US both unilaterally and through the Wassenaar Agreement, an international forum of 33 member countries, restrict the export of semiconductor equipment and materials that may be used for dual-purpose technologies (GAO 2002).

Japan during the early 1970s (Pecht et al 1999). Fifteen years later, China managed to master the 0.18 μm technology, just two years after the US implemented it. Although the comparison is based exclusively on foundry technology, an area the US has been retreating from, and therefore may understate the true technology gap, that China has been fast narrowing the technology gap is unquestionable.

A confluence of events has contributed to the rapid ascendancy of China's semiconductor industry. Industrial and S&T policies have played perhaps the most important role in jump-starting the industry and catapulting it to a fast growth track. Also critical has been the inflow of foreign direct investment, particularly Taiwanese investment, which has brought investment, technology and human talent to the Chinese semiconductor industry. An important although indirect factor has been the rapid growth of China's consumer electronics, computers, and telecommunication equipment industries that has generated insatiable demand for semiconductors.

The rapid growth of the electronics industry. The development of China's semiconductor industry is inextricably related to the rapid growth of the electronics sectors of consumer electronics, computers and peripherals, and telecommunication equipment. All these electronics products intensively use semiconductors such as integrated circuits. From 1991 to 2002, China's total industrial output of the electronics industry (at 1990 price) increased from 88.6 billion yuan to 1,780 billon yuan, thus averaging an annual growth rate of 31 percent (China Electronics Industry Statistical Yearbook 2003). That China has become the world's fastest growing electronics market – including the largest TV producer and the largest cellular phone market – has produced ferocious demand for semiconductors. According to the Semiconductor Industry Association, in 2003 China accounted for 11 percent of world demand for semiconductors and yet China's semiconductor industry was able to meet less than 20 percent of this demand.

The first major step the Chinese government took to rebuild its electronics industry was to turn over 100 military plants into dual-purpose (65 percent) or exclusively civilian (35 percent) plants (CIER 1991). The policy to convert military technologies and capabilities into civilian use produced phenomenal result. In 1984 a total of 6800 technology transfer contracts were signed to transfer defense technologies to the civilian sector with a transaction value of 430 million Yuan. In 1985 the transfer reached its peak of 1 billion Yuan. Electronics industry was a major beneficiary of this massive technology transfer that saw its output growing at an annual rate of 23.3 percent. Some of these military plants have later become giants in China's electronics sector such as Changhong Electronics in Sichuan Province.

Another major boost the Chinese government has provided to the electronics industry is the various national information technology infrastructure projects it started to implement in 1993. First among these are the four major "Golden Projects" (Pecht et al

1999) that include the Golden Bridge Project, the Golden Card Project, the Golden Customs Project and the Golden Taxation Project. The Golden Bridge Project reflects China's vision of an information superhighway. Its main objective is to provide an integrated telecommunications network system covering all of China through satellite and optical fiber networks. The main objective of the Golden Card Project is to institute a nation-wide electronic payment system that will expedite the adoption of credit cards, cash cards, and other forms of electronic payments. Chinese banks first issued credit cards in 1986. By the time the Golden Card project was initiated, the cumulate number of credit cards in circulation was four million. During the first three years of the Golden Card project begun in 1993 a total of 21 million cards were issued. The Golden Customs Project aimed to create a network that connected foreign trade companies with banks and China's customs and tax offices. In 1994 the government initiated the Golden Taxation Project to establish a computer network to facilitate tax collection. More recently in 2000 the Chinese police started building a nation-wide information network for the police force under the Golden Shield Project. These state-led initiatives have accelerated the diffusion of information technology across China.

China's semiconductor industry policy. When China started to rebuild its semiconductor industry in the early to mid 1980's, the industry was in a primitive state and was mainly engaged in producing low-end discrete semiconductors such as diodes and thyratrons; China possessed neither the capital nor the technology required to develop a modern semiconductor industry. To modernize its semiconductor industry, the Chinese government implemented Project 908. In 1994, Project 908 assisted a state-owned company, Huajing Electronics, acquire 0.9 μm technology from Lucent Technology. A year later, under Project 909, the Chinese government selected the Japanese firm NEC as the joint venture partner to build a wafer processing line in Shanghai that was capable of producing 20,000 8-inch silicon wafers per month. The production line represented a major jump for China's semiconductor technology – from 1-2 μm to 0.35 to 0.5 μm. A further joint-venture agreement with NEC saw the establishment in June 1998 of the Beijing Huahong NEC IC Design Co. Ltd. that added important design capabilities to China's nascent semiconductor industry.

Acquiring semiconductor joint ventures with leading foreign semiconductor firms has been one of China's key industrial development strategies. While in the early stage China insisted on a controlling interest in these joint ventures, increasingly new production facilities have been built by foreign wholly-owned semiconductor firms, particularly by Taiwanese semiconductor companies. Of the 21 semiconductor manufacturing plants currently operating in China, nine have been built during 2001 to 2004 and four of these are 100 percent owned by foreign investors (Howell et al 2003). SMIC (Semiconductor Manufacturing International Corp), based in Shanghai and founded by Taiwanese engineers and capital, launched a foundry facility to manufacture wafers using the 0.13 μm thereby placing China among the world's top semiconductor makers (Reuters News, 25 September 2004).

China's ambition to become a leading design and manufacturing base for integrated circuits was articulated in State Council Circular 18 published in June 2000. The Chinese government proposed a wide variety of policies aimed at attracting foreign investment in the semiconductor sector. Most critical and controversial of the incentives still in effect is the value added tax rebate that applies to semiconductors produced within China. China levies a value-added tax on imported semiconductors of 17 percent. But domestic designers and manufacturers receive a tax rebate that reduces the effective VAT rate to 3 percent on devices made and sold in China. Howell et al (2003) argue that Taiwanese manufacturers are largely attracted to mainland China by the tax incentive rather than manufacturing cost advantage. China has agreed to phase out the tax subsidy in compliance with WTO requirements[19]. In addition IC manufacturers can receive a 5-year tax holiday on the corporate income tax. Semiconductor companies set up in high-technology parks also benefit from all the preferential treatment in tax and infrastructure subsidies that these parks offer. In addition to central government policy, local governments, particularly those in Beijing and Shanghai, offered their own "Circular 18" on even more attractive terms. These policies represented a watershed in the development of China's semiconductor industry. From 2001 to 2003, a total of 19 Taiwan-invested foundries, including those by the world's top players, UMC and TSMC, were operational, under construction or being planned on the mainland compared to only 7 such startups in Taiwan during the same period. (Howell et al 2003).

China's semiconductor industry still faces serious challenges in acquiring IC design and overall new product development capabilities. Most of the technologies and equipment are purchased from foreign firms. However, in a highly cyclical world semiconductor market, China's fast growing electronics industry creates a stable and robust demand for China's nascent semiconductor industry. Given the rate of capital, technology and human talent inflow and the rapid technological progress that has taken place, the semiconductor industry perhaps represents one of China's best hopes of leapfrogging to the world technology frontier.

The standard's battle: techno-nationalism ? China's effort to promote indigenously developed technologies as industry standards has received wide attention[20]. Suttmeier and Yao (2004) interpret these developments through the lens of "neo-techno-nationalism" that is characterized as the pursuit of national interest by "leveraging globalization" and private-public partnership.

That the technology standards that China has been trying to promote broadly apply to the information technology industry is not simply a matter of coincidence.

[19] See www.ecommercetimes.com September 7, 2004.

[20] Suttmeier and Yao (2004) provide a list of these standards: Dragon Chip, Enhanced Versatile Disc, AVS (Audio, Video Coding Standard for MPEG), IGRS for communicating among digital devices, IPV6 (a new Internet protocol), RFID (radio frequency identification tagging), TD-SCDMA (Time Division Synchronous Code Division Multiple Access) for third – generation mobile communication technology, and WAPI (Wireless LAN Authentification and Privacy Infrastructure for mobile microprocessors).

China has made substantial progress in this industry by acquiring the technical capacity to develop its own technology standard. The actual and potential size of the Chinese market for information products considerably raises the stakes for standard setting in China. It is also important to recognize that the information technology industry is one that can be subject to substantial network externalities (Rohlfs 1974, Katz and Shapiro 1985). In such markets proprietary control of the industry standard can command lucrative rewards. For these reasons, China's recent attempts to influence the standard setting in various sectors of the information technology industry go beyond nationalism or national pride. Other governments have also intervened in standard setting. For example, in selecting the standard for high definition television (HDTV), Europe and Japan followed a centralized approach whereas the US relied on market forces (Farrell and Shapiro 1992). In the case of WAPI, China attempted to overturn the industry standard with a technology that was not necessarily superior. This was bound to meet with opposition. But given China's increasingly sophisticated technological capabilities and sustained economic growth, the Chinese government is likely to continue trying to leverage the size and anticipated growth of the Chinese market to influence technology standard setting to the benefit of Chinese firms.

6. What has been the impact of R&D on China's economy?

In this section, we present a broader overview of the some of the economic effects of China's growing S&T capabilities. We examine areas of impact: the returns to R&D, the role of technology transfer and its interaction with internal R&D, the factor bias of R&D in relation to China's comparative advantage, and the role of R&D in promoting product development and exports.

The returns to R&D. The value of high R&D intensity depends significantly on the returns that R&D investments generate. In Table 9 below, we summarize the results of a number of studies that have investigated the impact of R&D on a range of performance measure. These include cost, productivity, profitability, and new product development. All show robust returns to R&D. We review these studies below:

Hu and Jefferson (2004). Using a panel of approximately 1,000 industrial LME enterprises for 1991-1997 from the Beijing region, the authors employ panel data estimation methods to estimate three equations – an R&D expenditure equation, a production function, and a profit function. They find substantial and significant returns to R&D in the cross section dimension; however, they also find in their sample that the returns to R&D decline substantially over the sample period.

Cheung and Pin (2004). While the principal purpose of this paper is to estimate the impact of FDI on patent innovation in Chinese industry, the authors also estimate the returns of innovation inputs on domestic patent applications. Whether inputs are measured as S&T expenditure or S&T personnel, and whether estimated with fixed effects or random effects, the authors' results show that S&T inputs significantly expand creation of patent applications.

Jefferson, Bai, Guan, and Qian (2002). Using a recursive three-equation system, this paper investigates the determinants of firm-level R&D intensity, the process of knowledge production, and the impact of innovation on firm performance. Overall, the key statistical relationships are surprisingly robust, including the contributions of R&D expenditure to new product innovation, productivity, and profitability. Among the finding are that new product innovation accounts for approximately 12 percent of the total returns to R&D. Returns to industrial R&D in China appear to be at least three to four time the returns to fixed production assets. Across ownership types, the authors find that foreign firms exhibit unusually high returns to R&D in new product development, a result that most probably reflects their access to a wide range of products that are already produced by their parent companies for the OECD economies. State-owned enterprises on the other hand, while extremely inefficient in their ability to create new knowledge, appear to use new knowledge to their advantage. This result may represent the fact that SOEs tend to occupy industries, such as the tobacco industry, characterized by monopoly power; also, due to their relative initial inefficiency, large efficiency improvements may result from a small amount of restructuring effort.

Jefferson and Zhong (2004). Using a single cross section based on a survey of 1,800 firms, distributed over five Chinese cities and Seoul, the authors examine the impact of R&D personnel on firm productivity and profitability. Interacting a large number of firm and metropolitan-specific characteristics with R&D personnel, the authors identify a substantial list of factors that effectively complement the basic R&D operations of the participating firms. Complementary factors that effectively enhance the returns to R&D include the share of foreign ownership, location in an industrial park, proportion of the workforce with foreign experience, the purchase of outside technology, and the receipt of external R&D assistance. The most interesting finding is that among the five Chinese cities, Shanghai enjoys both the most extensive R&D capabilities and the highest returns to R&D. Its R&D capabilities and returns are more similar to those of Seoul than the other Chinese cities. The authors also find that the net returns to R&D personnel in the four Chinese cities exceed the returns to R&D personnel in Seoul.

Hu and Jefferson (2004). The authors use a panel of approximately 10,000 industrial LME's from 1995 to 1995 to estimate the direct and interactive impacts of R&D spending and technology transfer, i.e. the purchase of both domestic and imported technology. This paper examines the contributions of each of these avenues, as well as their interactions, to productivity within Chinese industry. At least for the scientific industries, in-house R&D significantly enhances productivity. The estimation results show that in-house R&D significantly complements technology transfer – whether of domestic or foreign origin. Foreign direct investment, which we assume is an important channel of proprietary within-firm technology transfer, does not facilitate the transfer of market-mediated foreign technology.

Fisher-Vanden and Jefferson (2004). This paper employs a panel of approximately 1,500 energy intensive industrial LMEs over the period 1997 to 2001. They use a translog cost function and fixed effects estimator to the estimate both the neutral and factor biased impacts of technology development expenditure on cost. Among the

authors' key findings is that in-house R&D exerts a significant neutral cost-reducing effect on production. They also find that imported technology tends to *increase* costs; the cost increasing effect of imported technology reflects the function of this technology, which is to facilitate new product development through the use of relatively capital-intensive production methods. A further key finding of the study is that in-house R&D exhibits a robust capital and energy saving and labor and material-using bias. These biases of deliberate technical change are consistent with China's underlying comparative advantage.

What have we learned from these studies? We emphasize several findings.

R&D has become an important strategic investment. Using different samples, different modeling methods, and different estimation techniques these studies consistently show robust returns to R&D. The consistency of these results leads us to conclude that the use of R&D resources is the result of deliberate, strategic intent that typically results in lower costs, improvement in product quality, and higher profits.

The returns to R&D depend on complementary factors. A central lesson from these studies is the importance of a range of complementarities for enhancing the effectiveness of R&D. The measure of innovation potential entails far more than a measure of the volume of R&D spending or R&D personnel. Factors that complement the effectiveness of R&D include the quality of training of R&D personnel and their managers, R&D networks with research institutes, universities, and overseas collaborators, and the institutional context of R&D, including the forms of corporate governance and public policy. By continuing to expand this set of R&D complements, the work by Jefferson and Zhong (2002) shows that China's enterprises and cities can further enhance the quality and intensity of firm-level R&D. Our own work finds that domestic firms that operate in FDI-rich industries tend to increase their R&D intensity more rapidly than other firms.

Internal R&D and technology transfer interact and complement each other in important ways. Multiple sources of technology development operate within China's economy.

- Hu and Jefferson find strong complementarity of internal R&D and imported technology – stronger for domestic firms than for FIEs.

- Fisher-Vanden and Jefferson find that in-house R&D focuses primarily on process innovation; imported R&D focuses more on product innovation.

R&D produces factor-saving biases that accentuate China's comparative advantage. Gilboy's analysis focuses largely on the role of R&D innovation in supporting China's export sector. Yet, high-tech exports account for barely more than four percent of China's total GDP.[21] The story of China's technological transformation is far more subtle than the development and export of high-tech goods.

[21] UNDP, 2000, calculated from the data on p. 199.

During the era of central planning, a mantra of China's political leadership was to catch up with the West. One way in which it pursued growth and a rise in living standards was to emphasize capital-intensive growth, which involved the establishment of an extensive set of capital-intensive industries, including steel, petrochemicals, and heavy machinery transportation equipment. An unfortunate result of this capital-intensive pattern of growth was that, in the absence of market signals, the allocation of China's scarce supply of capital was highly wasteful. Moreover, the pursuit of capital intensive growth that was fundamentally inconsistent with China's underlying comparative advantage in labor, not capital, created further inefficiencies that rendered Chinese industry incapable of competing on world markets.

This pattern of development appears to be changing. Two studies indicate that at least since the mid-1990s, innovation in China has tended to be labor using and capital and energy savings.[22] Enterprises that have spent the most on in-house R&D appear to be concentrating on installing new processes that are relatively intensive in their use of labor. One implication of this emphasis on the development and use of labor-intensive production processes is that China is using its relatively scarce resources – i.e. capital and energy – far more efficiently than it would if it were continuing along its capital and energy-intensive growth path.

That China is now developing and investing in relatively labor intensive and capital and energy-saving technologies, with the support of research and development, is an enormous achievement in its quest for economic efficiency and political stability. One consequence of greater efficiency and profitability is that retained earnings, the principal source of firm R&D spending in the OECD economies, is becoming more available to finance China's continuing rise in R&D intensity. At a time when funding for R&D from the Chinese government and banking sectors is in relative decline, growing efficiency and retained earnings are critical to sustaining the growth of China's R&D investments and its technological advance. This fundamental orientation – Chinese enterprises learning to capitalize on China's comparative advantage – is critical for establishing the foundation of an efficient, sustainable national R&D program while also moving China's economy up the technology ladder to expand its presence on international markets across an increasing variety of goods and services.[23]

7. How sustainable is the growth of China's S&T activity?

The sustainability of the growth and effectiveness of S&T activity in China will depend on both supply and demand conditions. Supply conditions involve the creation of S&T resources, both within China's domestic economy and their transfer from abroad.

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[22] Using a translog cost function approach, Fisher-Vanden and Jefferson (2004) find that in-house R&D is labor using and capital and energy savings. Jefferson and Su (2004) find that privatized enterprises invest in labor using technologies far more than unconverted state-owned enterprises.

[23] A particularly buoyant account of China's move up the technology ladder into foreign export markets is provided by Fishman (2004). A key point in that article is the ability of domestic producers to outcompete FEEs by establishing labor- intensive workshops that produce high-end domestic products and export goods of similar quality and at lower cost.

Domestic conditions focus on the continued growth of living standards and the growing sophistication and diversification of demand for products that match or exceed international standards. Neither size of the supply-demand equation is sufficient to understand the trajectory of R&D in China. In the absence of increasing demand for higher quality goods at lower cost, a growing supply of R&D resources, say driven by government policy, will only serve to depress the returns to R&D. Growing demands for R&D in the absence of corresponding increases in supply will raise the cost of R&D; thereby putting needed innovation beyond the reach of many firms.

Supply side factors include the large and growing supply of well-trained scientists and engineers. Among the factors that suggest that China has an abundant latent supply of R&D resources are:

- The number of engineers that China produces each year is four or five times that the U.S. This supply of domestically trained scientists, engineers, and researchers should continue to supply China's growing S&T needs.

- A substantial number of China's most academically gifted students study abroad. In order to attract and retain the services of these students who acquire training and experience abroad, Chinese government agencies, enterprises, research institutes, and universities will increasingly have to match international compensation standards.

- The creation of agglomerations of highly skilled S&T personnel in key universities, research institutes, and technology parks create the complementarities that can engage and retain the elite personnel required to staff and manage China's increasingly sophisticated S&T system.

- R&D intensification is narrowly based; it rests on the shoulders of a few cities/provinces and industries. Also, Table 5 shows that only 70% of the LMEs report R&D spending. The potential for many more firms to come on line is considerable. Considerable potential exists for whole provinces to substantially upgrade their R&D capabilities through policies that replicate and/or adapt the policies of the most successful regional innovators.

The demand for the production of more diversified, higher quality, and lower cost goods originates from two sources. One is the large and growing size of the Chinese market. For many of the same reasons that the U.S. served as the laboratory for the development of the automobile, air travel, and other revolutionary innovations, China, owing to its sheer size and prospect for continuing advances in its living standards, will continue to attract R&D resources and innovation. In addition, the growth of foreign export demand will also be critical to sustaining incentives for high rates of product and process innovation.

The ability to sustain these critical demand factors depends substantially on the ability of the Chinese government to maintain stable overall economic growth with

appropriate price stability. They also depend on the ability of China to continue to implement the provision of its WTO agreements, as the on-going reduction in trade barriers will motivate competition and export demand. As these factors drive increases in the present value of successful and timely innovation, firms will be motivated to shift their resources increasingly away from routine production to innovative activities.[24] The new innovations that result from growing R&D intensification feed into higher productivity and living standards, which in turn contribute to further shifts in the composition of demand toward technology-intensive goods and rising demand for innovations.

It is easy to imagine the process of self-reinforcing growth and technological change. In fact, however, the continuation of this process requires the necessary institutional context and incentives. Below we consider the present and potential institutional impediments to the growth of both the supply of and demand for S&T resources. Among the relevant considerations are:

- China continues to be an economy in transition. The role of planning and direct controls are likely to impede the pace and quality of innovation. For example, the continuing large numbers of yet-to-be reformed state-owned enterprises and reformed research institutes impede the quality of innovation. The persistence of non-performing debt seriously distorts the use of scarce capital needed for innovation, which prolonging the assignment of scarce capital and S&T resources to unproductive sectors of the economy.

- China's system of intellectual property rights is still unevenly enforced. The implementation of IPR, financial sector reform, and enterprise reform all depend in significant part on China's ability to conform to the goals and timetable associated with its membership in the WTO. Such compliance is important for fortifying China's nascent market institutions and creating a business environment that continues to be attractive to foreing investment, particularly high-tech investment with a strong complement to intellectual property rights.

- China has yet to establish an active venture capital market.

- China's R&D intensity may continue to rise, but given China's vast reserve of surplus labor, Chinese R&D is likely to sustain its labor-saving bias. This need to devise and adopt technologies that are capable of absorbing China's huge labor surplus may, at least at the margin, crowd out R&D resources that may otherwise the directed to basic research or result in the adoption of technologies that delay the adoption of state-of-the art technologies found in the most advance economies.

[24] See, for example, Aghion and Howitt, 1992.

- Differences between the cultural, legal, and political orientation of China and the U.S. may tilt the balance in China's favor, e.g., biomedical research involving the use of embryos.

Overall, if China is able to maintain growth with price stability while conforming to the expectations of its membership in the WTO, the existence of a relatively high elasticity of S&T resources should be able to sustain China's rising R&D intensity and continued technology development.

8. Caveats and conclusions

China has made striking progress over the past 25 years in reforming its S&T system and creating the conditions for successful R&D and sustainable technological development. The locus of R&D and innovation has moved from a system of state patronage to a largely market-driven enterprise system that has absorbed a substantial portion of the country's restructured research institutes and is complemented by a dynamic foreign sector.

The sheer size and geographic diversity of the economy – the proximity of certain coastal areas to Hong Kong, Taiwan, and OECD trade and FDI flows, while other regions are relatively isolated – will likely allow within China's borders for an unusually high degree of technological diversity. This diversity will propel China along multiple technology development tracks entailing a variety of technology outcomes. While several large metropolitan areas, principally along the coast, are developing the capabilities to approach the technological frontier of certain industries, the country's huge pool of surplus labor will move China along the path of a comparatively labor-intensive mode of production and growth. China's accession to the WTO and continuing integration with the world economy is likely to magnify this emphasis on China's comparative advantage in labor-intensive production.

The foreign sector is playing a critical role in promoting China's S&T development. Increasingly large numbers of foreign trained scientist and engineers are returning to China. Access to foreign technology motivates R&D operations that are needed to access and absorb these inflows of technology while also raising the return on internal R&D. By promoting competition and eroding the rents of established Chinese firms, the flood of FDI into certain industries is promoting the adoption and intensification of R&D operations in domestic firms. Finally, the establishment of foreign funded R&D centers, many as joint ventures or alliances with Chinese companies, has created the technical know-how, particularly in the electronics, telecommunications, automotive, and semiconductor industries, for Chinese companies and S&T personnel to engage with state-of-the art research.

China's S&T development and its on-going economic restructuring are mutually reinforcing. Many of China's high-technology companies grew out of murky ownership and property rights arrangements. Still, continued reform of the governance of China's enterprise and financial systems are needed to unleash the innovative potential of China's

emerging companies. Sustained technological change, in turn, propels rising living standards and the demand for increasing technological content in Chinese produced goods and services. The demand for technology-intensive production further reinforces the impetus for continued reform and institutional upgrading. For example, the growing demand for goods and services in technology intensive industries, such as telecommunications, software, and consumer electronics, spawns domestic constituencies that support the effective enforcement of intellectual property rights, which in turn is motivating new investment, both domestic and foreign, into these sectors.

The current model of technology import and imitation cannot in the long run sustain China's technological advance. As China narrows the gap with the world technology frontier, opportunities of easy gains from imitating will dissipate. To create proprietary cutting edge technologies, China will need a strong science base that will require more than liberalization and market competition. The Chinese government's continuous and deepened support for basic research and applied research of fundamental significance is needed to create the bedrock of an innovation system that will ensure sustained S&T success in China.

China is facing a golden opportunity to achieve technological catch-up with the West despite its relatively backward condition just 25 years ago. A fast growing domestic economy, a globalizing world economy that encourages the flow of capital and diffusion of technology, and a rich endowment of human talent are contributing to the prospect of China's S&T takeoff. However, significant barriers stand between China and a world technology power. If China succeeds in fortifying its market institutions, deepening on-going economic reform, and wisely applying S&T policy, China's emergence as a global technology power will be more than a possibility. These policies can help to sustain the virtuous circle of demand-supply interactions in the S&T arena that have brought China to the edge of S&T takeoff.

Table 1. Comparative measures of innovative intensity				
R&D expenditure/GDP[1]	**1991**	**1995**	**2000**	**2001 ('03)**
China	0.74	0.60	1.00	1.09 (1.3)
USA	2.72	2.51	2.76	2.82
Japan	2.93	2.89	-	3.09
Korea	1.92	2.50	-	2.96
Taiwan	-	1.78	-	2.16
Brazil	0.46	0.69	1.05	-
India	0.85 ('90)	0.77('96)	0.86 ('99)	-
Country	**China**	**USA**	**Japan**	**Korea**
Basic research (% total R&D)	5.0	18.1	12.3	12.6
R&D funds (% enterprise funded)	57.6	66.2	73.0	72.5
Scientists and eng. per 10,000 pop.	10	90	100	62
Patents (approved by USPTO)	**1991**	**1995**	**2000**	**2003**
USA	51,177	55,739	85,068	87,901
Japan	21,025	21,764	31,295	35,517
Taiwan	906	1,620	4,667	5,298
Korea	405	1,161	3,314	3,944
France	3,030	2,821	3,819	3,869
Italy	1,209	1,078	1,714	1,722
India	22	37	131	341
China	50	62	119	297
Brazil	62	63	98	130
Export quality				
High technology exports as a % of mfg exports (2002)				
China	**1990 (6%)**	**1994 (11%)**	**1998 (17%)**	**2002 (23%)**
Low income (4%)	**2002**			
Low-middle income (17%)	**India**	**Russian Fed**	**Thailand**	**Brazil**
	5	13	31	19
Upper-middle income (21%)	**Malaysia**	**Hungary**	**Mexico**	**Argentina**
	58	25	84	7
High income (23%)	**U.S.**	**Japan**	**Korea**	**Taiwan**
	32	24	32	42
	1972	**1981**	**1991**	**2001**
% exports to US that overlap with OECD exports to U.S., (Schott, 2004)	0.09	0.28 (10)	0.55 (4)	0.75 (3)**

[1]NBS/MOST, 2003.

*Manufacturing export similarity indexes with the OECD.

**after Mexico (0.80) and Korea (0.80).

Table 2. The role of changing industry composition (LME database)				
Industry	R&D/VA 1995 (%)	R&D/VA 2000 (%)	R&D/VA 2000/1995	Sales share 2000/1995
Elec. and telecom. equipment	2.97	7.34	2.49	1.91
Elec. equip. and machinery	1.71	4.98	2.91	1.15
Instruments and meters	2.86	4.65	1.63	1.28
Total industry	1.52	1.98	1.29	1.00

Source: Jefferson, Bai, Guan, and Yu (2003). Note: VA = value added.

Table 3. Distribution of R&D/VA (r), all enterprises (%)							
Year	0	0<r£1	1<r£2	2<r£4	4<r£6	6<r£10	r>10
1995	79.8	7.2	3.2	3.4	1.4	1.7	3.3
2001	70.9	6.7	4.0	4.8	3.0	3.5	7.1
% increase	-11.1 (45.6)	-7.5	22.8	40.8	108.0	110.8	119.1

Source: NBS-LME data set. Note: The figures in parentheses represent the share of total LMEs that fall within each percentile range of R&D/intensity.

Table 4. Regional comparisons, 2002 (billion yuan)		
	R&D expenditure	% total
Total	128.8	100.0
Mid-region	20.9	16.2
Western region	17.0	13.2
Eastern region	91.6	71.1
Of which:	-	-
1. Beijing	22.0	17.1
2. Guangdong	15.6	12.2
3. Jiangsu	11.7	9.1
4. Shanghai	11.0	8.7
Total 1 - 4	60.3	47.1

Table 5. Comparison of Seoul and 5 Chinese cities				
City	Composite index of R&D capabilities	Estimated returns to R&D personnel ($) (1)	R&D personnel wage ($) (2)	ratio 1:2
Seoul	31.88	37,639	20,847	1.81
Shanghai	25.15	24,086	5,655	4.26
Guangzhou	6.63	14,984	3,249	4.62
Beijing	0.00	13,479	3,494	3.86
Chengdu	-7.92	9,676	3,102	3.12
Tianjin	-10.26	8,818	1,569	5.62

Source: Jefferson and Zhong (2004), Table 9.

Table 6. Technology measures: coastal vs. interior (LME enterprises)						
	Coastal provinces			Interior provinces		
Performance measure	1995	2000	1995-2000	1995	2000	1995-2000
	mean	mean	annual growth (%)	mean	mean	annual growth (%)
Productivity	6.27	7.22	2.81	4.57	4.86	1.20
Per worker measures:						
Profit (yuan)	25.36	34.95	6.41	13.73	16.67	3.88
R&D/worker (yuan)	0.32	1.74	33.58	0.24	0.63	19.27
Patents/worker (10^{-4})	1.83	6.88	26.49	1.18	2.31	13.43
New product sales (yuan)	16.08	38.57	17.49	7.89	9.80	4.35
Foreign assets (yuan)	0.09	0.12	5.84	0.02	0.02	2.84

Jefferson and Su, 2002

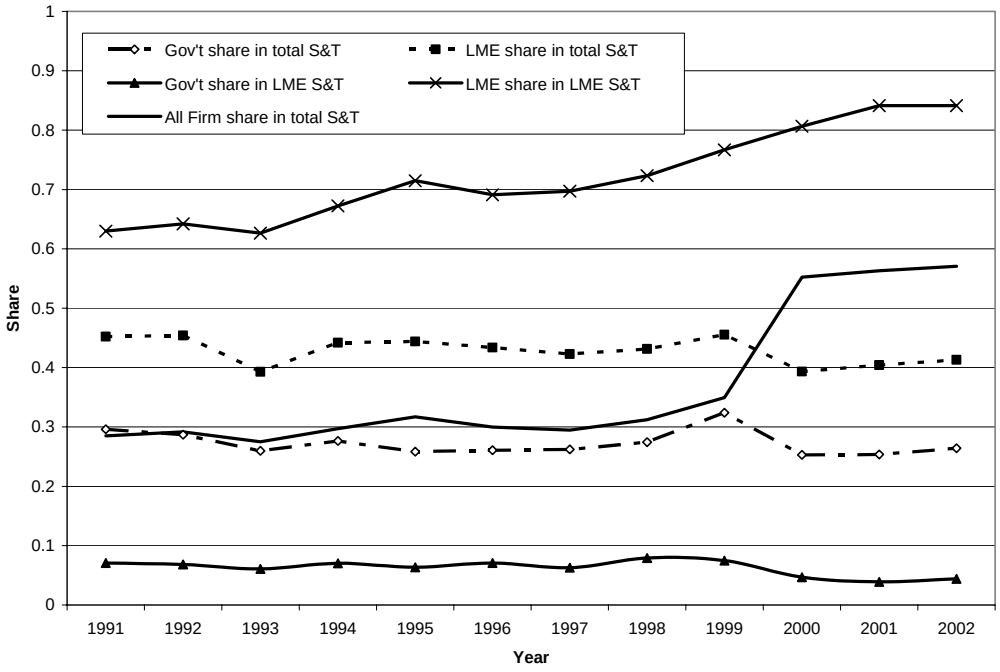
Table 7. Domestic vs. foreign contributions to R&D spending (Industrial LMEs)		
	Domestic	Foreign/ HKT
1995		
Firm count	16,823	1,323
R&D exp (‘000s)	67,130	6,480
R&D/value added	1.11	0.99
2001		
Firm count	14,429	4,360
R&D exp (‘000s)	281,770	53,380
R&D/value added	3.29	2.63
2001:1995		
R&D exp	4.19	8.23
R&D/value added	2.96	2.66

Table 8. Major national science and technology programs							
			Funding (100 million)		Performing sector (%)		
Program	Year started	Focus and objective	Total	State share (%)	Univ	RIs	Firms
Climbing	1992	Basic research	171.02	95.02	24.8	75.2	0
"863"	1986	Catch-up with the West in selected areas of fundamental and frontier research	1,004.21	52.05	29.8	35.6	28.7
Key Projects	1982	Applied research and development to meet critical technological needs in key sectors of the economy	2886.52	42.24	16.2	46.9	27.1
Torch	1988	Commercialization of new technologies; entrepreneurship through incubators and science parks	28993.04	1.77	0.7	3.0	95.3
Spark	1986	Diffusion and adoption of technologies in rural China	14752.67	4.14	0.2	4.5	87.9
National Natural Science Found-ation	1986	Basic and applied research	1004.01				
National Key Laboratories	1984	Basic and applied research	950.12				
Extension	1990	Diffusion and adoption of new technologies	4011.73	6.28	0.8	5.0	81.9

Sources: Yuan et al (1992)

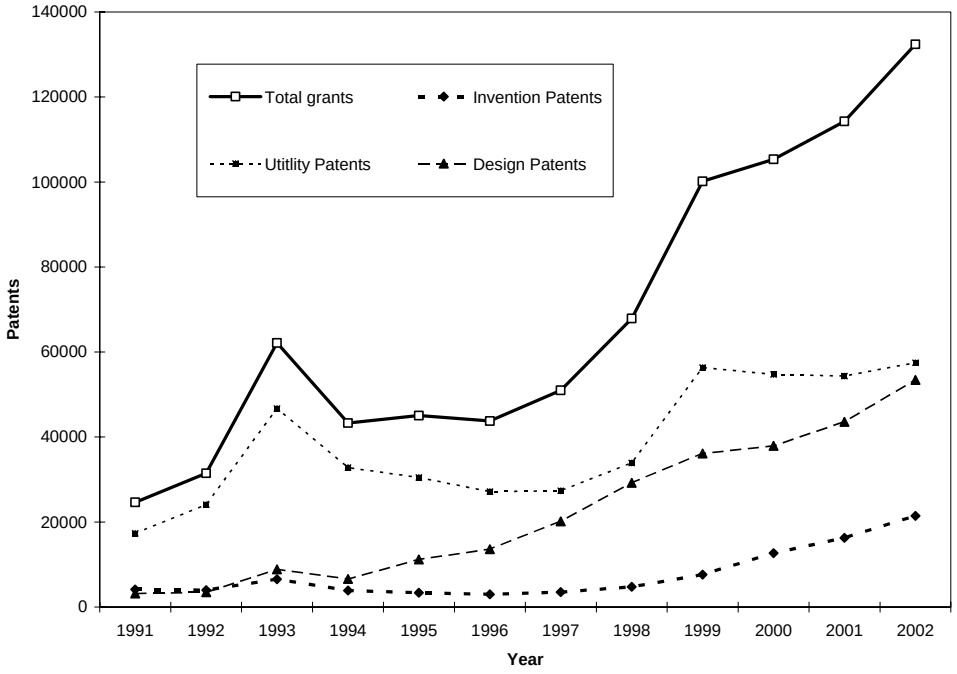
Table 9. Returns to R&D			
Study	Data	Functional form; estimation method	Key findings
Hu and Jefferson (CER)		Production function; OLS	A positive elasticity of TFP w.r.t. R&D personnel;
Cheung and Lin (CER)	Provincial level data		A positive elasticity of patent production w.r.t. S&T personnel;
Jefferson, Bai, Guan, and Yu (EINT)	5,451 LMEs	Production function;	A positive elasticity of TFP w.r.t. to R&D personnel; variations in the orientation and effectiveness of R&D across ownership types.
Jefferson and Zhong (World Bank)	1,800 surveyed firms in 5 Chinese cities and Seoul	Production function; OLS	A positive elasticity of TFP w.r.t. R&D personnel; emphasis on the complementarity of a large number of firm level, S&T network, and public policy variable in enhancing the impact of R&D.
Hu and Jefferson (REStat)		Production function; IV	A positive elasticity of TFP w.r.t. R&D personnel; Highly significant interaction terms between R&D and imported technology.
Fisher-Vanden and Jefferson		Cost function; fixed effects	R&D negative cost elasticity w.r.t. technology development spending; positive cost elasticity w.r.t. imported technology. R&D biased toward saving capital and energy; using labor and materials.

Figure 1 The roles of state and enterprises in S&T funding



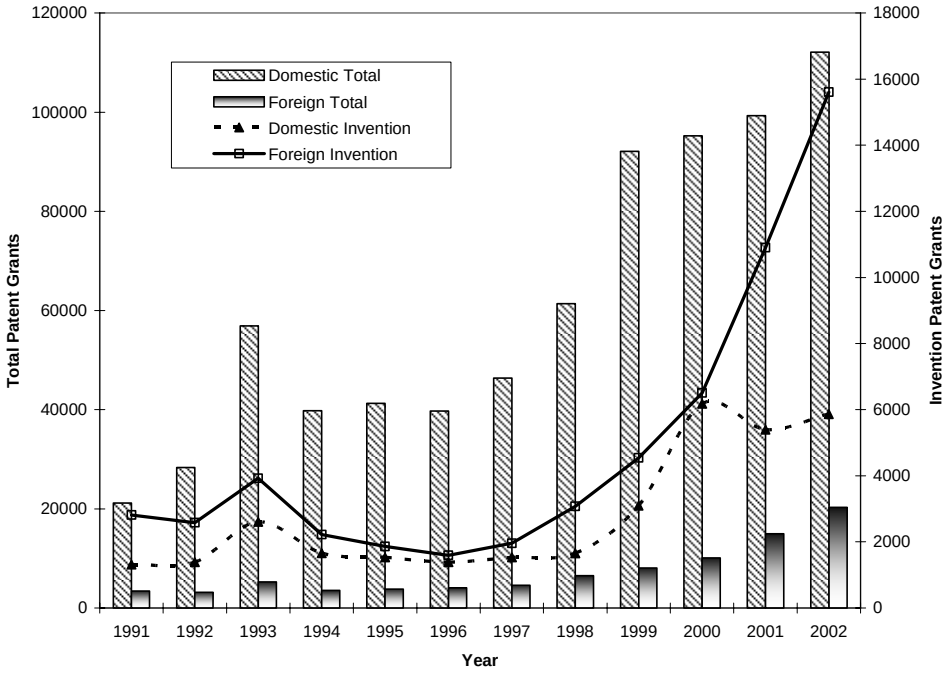
Source: China Statistical Yearbook on Science and Technology (2003)

Figure 2 Patents and scientific papers



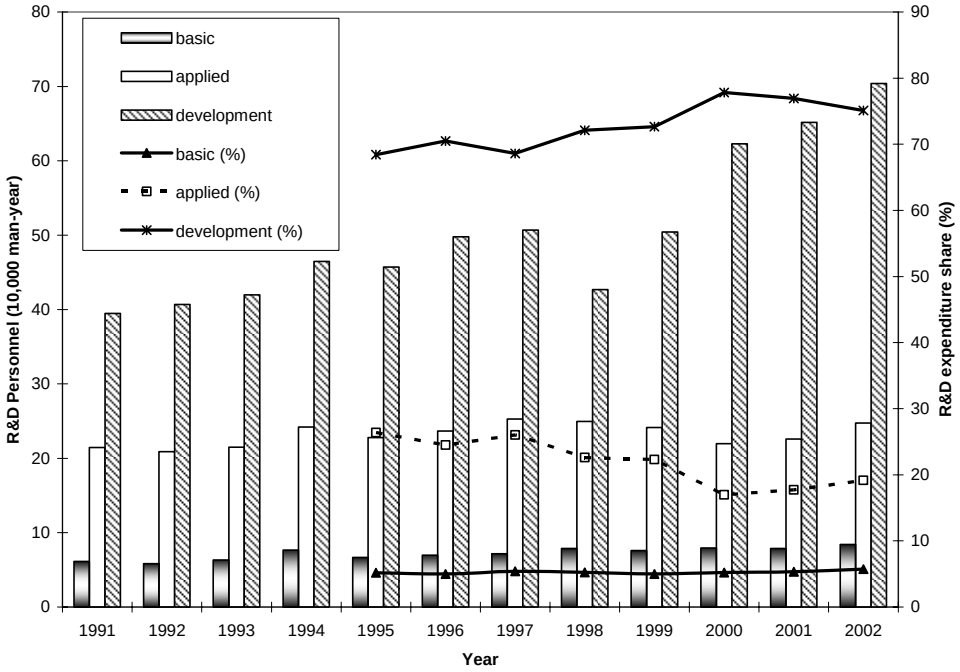
Source: China Statistical Yearbook on Science and Technology (2003)

Figure 3 Domestic vs. Foreign Patent Grants



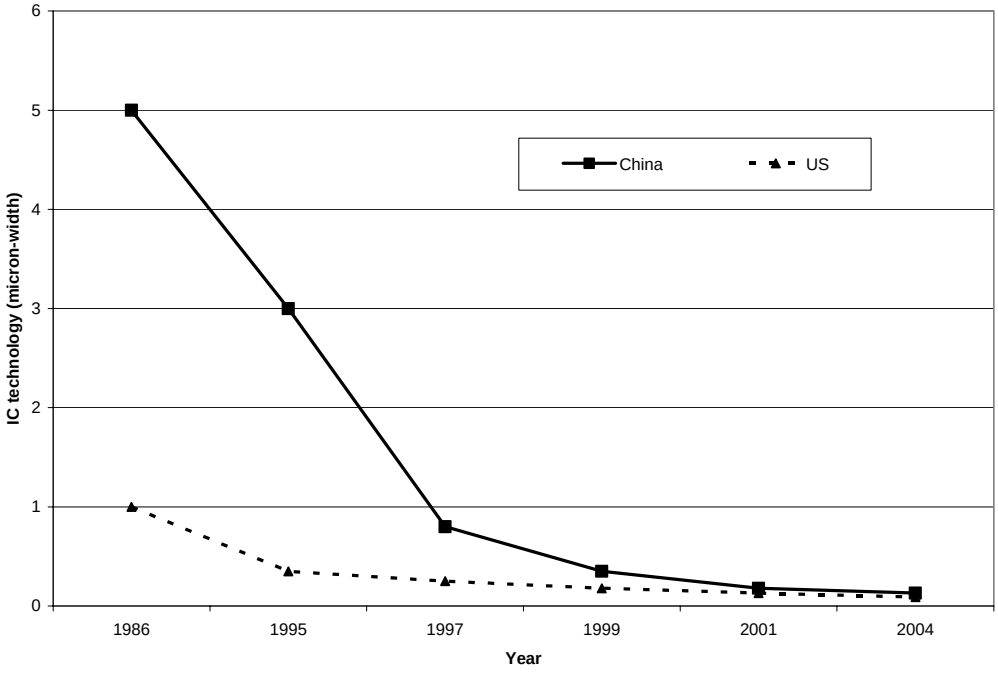
Source: China Statistical Yearbook on Science and Technology (2003)

Figure 4. Full-time Equivalent R&D Personnel and R&D Expenditure shares



Source: China Statistical Yearbook on Science and Technology (2003)

Figure 5. US - China Semiconductor Technology Gap



Source: GAO (2002)

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