Science and Technology in China[1]

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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, through its own technological innovations, or, most likely, through a combination of adoption and innovation. The purpose of this chapter is to describe and analyze China's science and technology (S&T) capabilities and the economic, institutional, and policy context that together are shaping the range and growth of these capabilities. We conduct this analysis against the background of a large and fast-growing literature on the subject.

China's national innovation system is making two transitions – from plan to market as it moves away from a centrally directed innovation system and also from low-income developing country toward Organisation for Economic Co-operation and

Development (OECD) industrialized country status as it intensifies its innovation effort and more effectively deploys the ensuing technological gains.

Many of the impulses and policies of China's current S&T system are legacies of the nation's traditional economy going back to the nineteenth century and before. These include the recognition that access to Western S&T is critical to China's economic modernization and the consequent openness to foreign technology, advisors, and investment, particularly in special zones in the coastal areas. While the socialist era largely insulated China from these overseas influences, save for its reliance on technology, advisors, and investment from the Soviet Union during the 1950s, throughout the three decades of that era, China maintained a relatively high level of S&T effort with an eye toward catching up to the West. Even so, with few exceptions, China's overall technology gap with the West grew substantially over this period. The section "China's S&T System in Historical Perspective" focuses on the role of China's traditional and socialist eras in shaping the S&T system of present-day China.

In the section "China's S&T Level in International Context," we situate China within a comparative context that examines levels and trends of S&T activity – both inputs to innovation and S&T outputs. While starting from low levels, China's rate of advance in research and development (R&D) spending in relation to its gross domestic product (GDP) and patenting activity, particularly when we include patents by foreign firms, indicates strikingly rapid progress. Against the backdrop of the

S&T takeoffs of the large OECD countries and Asia's Newly Industrialized Countries (NICs), we inquire whether China has begun its S&T takeoff. We return to this issue in the section "How Sustainable Is the Growth of China's S&T Activity." The quickening pace of S&T activity in China is not synonymous with a comparable increase in innovation quality. China still lags well behind its OECD counterparts in the proportion of R&D spending that it devotes to basic research and the citations it receives for its scientific publications. The disproportionate emphasis on applied research is reflected in an overwhelming preponderance of utility patents that are typically viewed as proxies for imitation. China remains a substantial distance from the world's innovation frontier.

As a low-income centrally planned economy, government-funded research institutes and state-owned enterprises that responded to innovation directives were at the center of China's pre-reform S&T system. Since the reform, China's S&T system has exhibited a rapid shift in S&T resources to sources of innovation that increasingly lie outside the state sector. This shift, which we examine in the section "The Shifting Locus of R&D Activity" is visible in the growing portions of R&D spending accounted for by the enterprise sector, particularly the nonstate sector, the restructuring of China's research institutes, and the growing role of universities as a critical locus of research activity. Over these past two decades, the role of the government in promoting and financing technology innovation has changed dramatically.

A central feature of China's economic transformation is the extensive role of the foreign sector. Nowhere has this been more evident than in the numerous vehicles that have developed to facilitate technology transfer – trade, foreign direct investment (FDI), foreign-funded R&D, and markets for the import and sale of foreign technology. Some analysts argue that the research activities of the foreign sector dominate those of the domestic sector, which itself exhibits anemic innovation capabilities. While our perspective grants critical importance to the foreign sector, our view is that rather than through direct spending on R&D, its principal contribution operates through the channel of FDI that creates both competition and technological opportunity that in turn motivates Chinese firms in an effort to survive to spend resources on R&D and innovation. The role of the foreign sector is the subject of the section "Conrtibution of the Foreign Sector."

The governments of all the large, successful innovation economies in the OECD play an active role in shaping innovation incentives and directing resources to R&D. China follows this pattern, increasingly through indirect channels, but also through direct means in areas that are deemed to be critical to the nation's technological goals. Over these past two decades, the role of the government in promoting and financing technology innovation has changed dramatically. One example of this change is the substantial phase out of direct government subsidies for R&D in the enterprise sector in favor of indirect instruments, such as tax credits. A range of programs that are intended to promote innovative effort and encourage technology transfer are described in the section “Government Policies and Programs in Support of S&T.”

Innovation efforts – whether successful or unsuccessful – typically involve the interplay of a complex set of factors and players. As a large, open, technologically ambitious, yet transitioning economy, China’s pursuit of technology advance is a particularly vigorous and encompassing undertaking. In the section “Case Studies,” we attempt to illustrate the interaction of domestic and foreign and government and private players and resources within an extraordinarily heterogeneous regional, institutional, and technological environment. We illustrate this range of circumstances that shapes technological advance with two industry case studies – the semiconductor industry and the automobile industry.

Because R&D is undertaken to enhance firm performance and innovation, the section “What Has Been the Impact of R&D on China’s Economy?” reviews the literature assessing the impact of R&D on key measures such as productivity, profitability, and patenting. This section also examines the impact of complementary factors, such as educational levels and overseas collaboration, as they enhance R&D returns, the interactions between internal R&D and technology transfer, and the factor bias of R&D, that is, the extent to which R&D used by China’s industrial enterprises results in choices of factor intensities that are consistent with China’s underlying comparative advantage.

Over the past two decades, in particular since 1995, when China's R&D spending to GDP ratio has risen from 0.6 to 1.4 percent, China has given the unmistakable appearance of a country that is on the path to closing the gap with most of the OECD economies. Indeed, in its current Tenth Five-Year Plan, China's government has set 2015 as the date for the country to achieve the plan's goal of an "innovation economy." Many conditions, including China's openness, size, and emerging S&T class, all suggest that this goal is achievable. And yet, China remains a developing economy with the majority of its population still at or near subsistence living standards. Even if China is on an inexorable road to OECD levels of S&T intensity and achievement, this path may take more years than the leadership would hope. While South Korea required only five years to transition from the levels of R&D intensity of a developing economy to OECD levels of R&D intensity, the same trajectory required nineteen years for Japan. In the section "How Sustainable Is the Growth of China's S&T Activity," we assess the conditions that seem to be pushing China toward OECD style levels of S&T activity. To do this, we draw on a unique data set that provides detailed information about the production, financial performance, and R&D activity of China's approximately 23,000 large- and medium-size industrial enterprises.[2]

Finally, as suggested at the beginning of this introduction, the topic of S&T activity in China is a fast-changing and growing field. In the final section of this chapter, we draw conclusions from our analysis and also raise questions and speculate on some of the important but still imponderable issues that will determine China's S&T future.

2. CHINA'S S&T SYSTEM IN HISTORICAL PERSPECTIVE

Patterns of China's current S&T development are in part shaped by China's historical experience – both technological development in the traditional, pre-1949 economy and the S&T system that emerged during the socialist period. We focus on the features of these earlier periods that help us to understand the strengths, weaknesses, and institutional and policy orientation of China's now evolving S&T system.

The Pre-1949 Period

Joseph Needham has documented the prodigious scientific achievements of China during ancient and imperial times.[3] While paper, printing, the compass, and gunpowder are celebrated as the four great inventions of ancient China, Chinese inventors also made substantial strides in agricultural technology and astronomy.[4]

A continuing subject of debate among scholars of Chinese history is why China did not develop a scientific revolution and why during the nineteenth century China fell behind Europe. Some contend that China did accomplish its own scientific revolution in the seventeenth century.[5] Others argue that China's political system was hostile to scientific progress, a perspective refuted by Benjamin Elman.[6] More recently, historians have questioned political and cultural explanations and have instead focused on economic causes. One intriguing economic explanation, advanced by Elvin (n.d.), is that China's labor abundance caused it to enter a "high-level equilibrium trap" that impeded the mechanical revolution spawned in the West (Elvin, n.d.). According to this interpretation, the nonmechanized processes in agriculture and industry were so well developed and efficient that they outcompeted early mechanized processes, thus making capital investment in mechanization unprofitable. The "trap" presages China's contemporary condition in which the continuing abundance of labor resources shapes the technological choices it faces today, including the tension between exploiting homegrown labor-using technologies and the import of more capital-using, labor-saving technologies employed in the advanced OECD economies.

Lin (1995) offers an alternative interpretation, which is based on his distinction between two modes of innovation: technological inventions that stemmed from the experiences of artisans and farmers that dominated in premodern times and scientific innovations that mainly result from modern experimentation cum science. Lin hypothesizes that China enjoyed a comparative advantage in premodern times, while Europe during the scientific revolution changed to planned experimentation for its scientific advance. China was slow in making the transition, according to Lin, due to the content of China's civil service examinations and criteria for promotion, which distracted the attention of intellectuals away from investing in the human capital necessary for modern scientific research.

Whether Elvin's "high-level equilibrium trap" or Lin's distraction hypothesis explains China's loss of its technological advantage, once lost, China's intelligentsia exhibited a set of distinctive attitudes and strategies that shaped its adoption of Western technologies beginning in the nineteenth century. With China weakened by the demands of the Taiping Rebellion (1850–1864), notable figures in the country's military and scholarly classes formulated the "self-strengthening" (*ziqiang*) movement that advocated making selective use of Western technology. In 1864, patrons of the movement[7] dispatched the first Chinese citizen to have graduated from an American university back to the United States to purchase the equipment needed to establish an arsenal near Shanghai. With the help of Western technicians the arsenal successfully refurbished a foreign steam engine in 1868 and launched the first Chinese steam-powered vessel. Soon thereafter, modeled after the Shanghai arsenal, a second arsenal was built in Fuzhou, and schools were founded, under the direction of foreign advisors, "for the study of mechanical skills and navigation … (while) translation projects for technical works were started on an ambitious scale" (Spence, 1991, p. 199 .

Later, following the Sino-Japanese War (1894–1895), the Western powers further expanded their economic influence. According to Spence, "… Western powers had imposed their presence on China and were now beginning to invest heavily in the country, especially in mines, modern communications and heavy industry …" (Spence, 1991, p. 224). While embracing the virtues of China's essential philosophical values and traditions, China's intellectuals further recognized the critical role of Western technology, which gave rise to the *ti-yong* movement (combining "essence" and "practical use"). Holding on to the belief that the essence of Chinese civilization would endure, influential elements of China's scholar-official class then believed that China should proceed to quickly adopt all sorts of Western practices to be facilitated by the hiring of Western advisors (Spence, 1991, p. 226).

This ambitious vision of technology transfer was frustrated during the first half of the twentieth century by a succession of weak central governments, the Japanese invasion in the 1930s, and by civil war. Nonetheless, the self-strengthening and *ti-yong* movements represented the underlying intellectual and moral foundations for China's quest for Western technology, investment, and advisors as vehicles for restoring the technological and economic vitality of Chinese society. These early patterns of encounter with Western technology founded on the impulse of China's intelligentsia arguably presaged the current openness to Western technology as represented by China's large and growing trade ratio, robust FDI, active markets in imported foreign technology, and proliferating special economic zones. Furthermore, the potential reasons for China's relative technological decline – its labor abundance and success at localized incremental innovation and imitation – remain central to its model of technological progress today.

The Socialist Era[8]

From the 1950s through the 1970s, despite being a low-income country, China pursued a strategy of high S&T effort. With the Soviet Union as its model during the 1950s, China not only incorporated basic Soviet technologies, but also adopted centralized organizational structure for the entire national system of research and innovation. China mobilized available intellectual resources, particularly for defense purposes, and created elite research institutes, notably in the Chinese Academy of Sciences (CAS). 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.

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. This system was effective in supporting basic research, where despite low private returns, the social returns and hence the attention and accolades afforded by the government were high. However the components of socialist institutions and policies could not 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 operating outside the immediate realm of the government's S&T priorities.

While industrial innovation did occur in the enterprise sector, the emphasis on assigning quantitative innovation targets to industrial enterprises, as well as the absence of a price system that reflected underlying scarcities seriously compromised the economic value of the mandated innovations. When Jefferson and Rawski interviewed a senior engineer at the Beijing No. 1 Lathe Factory, who had participated in the factory's technology development program during the 1970s, he explained that the motivation then was solely to fulfill (or exceed) the plan targets, believing that such compliance would enable China to catch up with the West. No serious assessment was made of the economic impact of innovations on productivity or profitability, since no economically meaningful measure of these accounting categories then existed.

When China and the Soviet Union abruptly split in the early 1960s, China was cut off from its technology source at a time when it had no alternative technology partners and very little market access to technology. Thus, China approached a state of technology autarky for a decade from the mid-1960s through the mid-1970s. During this period, China's strategy was to import a handful of factories that embodied specific industrial technologies and then reverse engineer and replicate them domestically. A few key technologies in metallurgy and synthetic fibers were transferred in this way, and incremental improvements were made on some Soviet-legacy technologies, such as electricity generation, where equipment was scaled up to larger more efficient units.[9]

China's inability to achieve more than a modest rise in living standards during the quarter century after 1949 reflects the relative ineffectiveness of the innovation system. Specifically, according to Chow (1985) in 1979, total factor productivity in the agricultural sector was lower than it had been in 1952. Over a similar period, from 1957 to 1978, Chen et al. (1988) report that multifactor productivity in the industrial sector rose at a rate of just 0.4–1.1 percent per annum.[10] While China had made notable advances in a few areas, overall the S&T gap between China and the West grew during the socialist era.

Two legacies of China's socialist-era S&T system stand out. First, the highly centralized system of innovation concentrated China's research capabilities within government institutions, leaving China unable to develop a broad-based set of research capabilities that could sustain the broad-based productivity growth needed to raise living standards. A second legacy was the treatment of invention as a public good. China's socialist system was antithetical to a culture and the requisite institutions (e.g., patent laws, royalties, and courts) necessary for the creation and protection of intellectual property rights. Reliance on state patronage for innovation and the absence of an intellectual property rights tradition remain as legacies that hinder the creation of a robust national innovation system.

The Reform Period

China’s reform of its national innovation system is in key respects similar to the “growing out of the plan” scenario that has characterized much of China’s economy since 1979. This is certainly true for the enterprise sector. The most important change in the enterprise sector, arguably, was the entry of new enterprises – joint ventures and wholly owned foreign enterprises, township and village enterprises (TVEs), and other nonstate enterprises – which created severe competition across many industries. The resulting erosion of profit margins motivated many enterprises to search for new process and product innovations needed to enable survival and continuing wage increases.

Nonetheless, while China’s enterprises increasingly established their own independent R&D operations, by 1990 the share of the enterprise sector in total national R&D spending still amounted to only about one-half the typical enterprise share in the OECD economies. Furthermore, within the enterprise sector, nearly two-thirds of total enterprise R&D spending was still controlled by state-owned enterprises. At the same time, more than 5,000 research institutes that accounted for one-third of the country’s scientists and engineers remained largely under the supervision of one or more government agencies and fundamentally unchanged throughout the 1980s and most of the 1990s.

By 2000, these conditions had either changed dramatically or were on the path toward fundamental change. In 2000, 60 percent of the country’s R&D spending was funded and performed by the enterprise sector, comparable to that of most

OECD economies. Moreover, with the acceleration of ownership restructuring in the later half of the 1990s, by the year 2000, the majority of enterprise-funded R&D was performed outside the state-owned enterprise sector.

The restructuring of China's more than 5,000 research institutes also became a priority during the late 1990s. Under the reform initiative that began to be implemented in 1999, government research institutes were converted to nongovernment S&T enterprises and non-profit research institutes. The financially self-sufficient enterprises and institutes were to decide by themselves what direction their research should take and become responsible for whatever profits or losses they incurred. During 1999–2004, through conversion and consolidation the number of government-financed research institutes fell from 5,573 to 3,973.[11]

During the reform era, China at first tried to keep government R&D outlays high. However, with government SOE revenues eroding and the budget's share of GDP declining, the country struggled to sustain R&D spending as a proportion of GDP. In 1987, China invested only about 0.7 percent of GDP in R&D; in 1994, the intensity slipped further to below 0.6 percent. By this time, China was beginning to look like a "normal" low-income country, with R&D outlays at or even below the level that cross-country comparisons adjusted for living standards would indicate. But wanting to drive China's S&T advance, China's policymakers actively sought to raise the ratio of R&D to GDP. After 1996, levels of R&D intensity began a sustained raise; by 2006, the reported R&D ratio rose to 1.4 percent, more than twice its level of 1994 (Wang, 2007).

Beginning in the 1980s and continuing into the 1990s, China's government formulated a series of programs that were designed to establish the central government as a major contributor to basic research while also promoting technology diffusion. More than any other broad government-funded R&D programs, the *863 Program* and *973 Program* focused on enabling China's S&T capabilities to catch up with those of the OECD countries. While these programs largely focus on basic research and frontier technologies, the *Torch Program* supports high-tech industries, and the *Spark Program* focuses on invigorating China's rural economy through the appropriate application of S&T. Since the Torch Program started in 1986, there have been 150,000 technological projects nationwide, covering 90 percent of China's counties.[12] In addition, China's government provides direct R&D grants and tax incentives to industry. Over the past decade the latter have grown to increasingly supplant the former. Finally, in an effort to nurture innovation the Chinese government in 1985 reinstated its patent law, followed in 2001 by its accession to the World Trade Organization (WTO) and signing of the Trade-Related Aspects of Intellectual Property Rights (TRIPS) Agreement.. By the early years of the 2000s, China's national innovation system had acquired many of the attributes that might be expected of a large newly industrializing economy.

In the following sections, the discussion primarily focuses on the development of China's S&T system since 2000.

3. CHINA'S S&T LEVEL IN INTERNATIONAL CONTEXT

To assess China's progress in the arena of S&T, we first compare China's level of S&T activity with the levels of other countries – both OECD countries and other emerging industrial economies. Our comparison focuses on three measures of innovation effort and three measures of S&T achievement. First, we measure the intensity of R&D inputs.

Measures of Innovation Effort

Among the numerous measures of R&D effort, those for which coverage is most comprehensive and consistently reported, are the ratio of R&D expenditure to GDP, the proportion of scientists and engineers in the total population, and the proportion of R&D dedicated to basic research.

R&D Intensity

The data in Table 9.1 show that China's R&D intensity sharply accelerated during 1995–2000 and continued to rise into the current decade. Hovering in the range of

0.60 in 1995, by 2006, China's R&D intensity rose to 1.4 percent. By comparison, the R&D intensity of most OECD economies and Taiwan lay in the range of 2–3 percent.

Insert Table 9.1 here

For China, this level of R&D intensity is high given its living standards. Among the world's low- and low-middle–income countries, China has been the only country whose level of R&D intensity has risen beyond 1 percent.[13] While Brazil, a middle-income economy, exhibits a similar pattern of rising R&D intensity, its level of (exchange-rate-adjusted) per 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.

Figure 9.1 shows the trajectories of R&D intensification across the largest OECD countries, Taiwan, and Singapore, all of which exhibited rapid increases in their ratios of R&D spending as a share of GDP. The figure confirms that China's R&D intensity has risen rapidly from 1996 to the range of 1.2–1.3 percent, having outpaced the rise in R&D intensity of Brazil and India. In the section "How Sustainable Is the Growth of China's S&T Activity," we return to these patterns of R&D takeoff shown in Figure 9.1 and attempt to identify the factors responsible for the acceleration of R&D expenditure in relation to GDP.

Insert Figure 9.1 here

Scientists and Engineers

According to *China's Statistical Yearbook on Science and Technology*, 2004, in 1998, China had 12 scientists and engineers per 10,000 population; by 2004, the ratio had risen to 15 (NBS/MOST, 2006, p. 348. As shown in Table 9.2, this ratio is notably less than those of Japan (102), the United States (90), Korea (67), and Italy (29). At 10, only Turkey (data for 2002) lagged behind China (data for 2003) in this measure. Nonetheless, because of its large population, the sheer number of scientists and engineers in China exceeds the numbers for all countries except the United States whose totals China is also likely to surpass soon. In 2003, China graduated 54,557 scientists and engineers with degrees at the master's level or above. In that same year, however, 137,181 students enrolled in science and engineering programs at the master's level and above (NBS, 2004, p. 20, 22). This increase in matriculating students relative to graduating students underscores the extraordinary growth in Chinese higher education in the fields of science and engineering.

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Basic Research

Although the intensity of R&D in China's economy is rising sharply and approaching that of certain OECD counties, the basic research component of these funds is substantially less than that of their OECD counterparts. Table 9.2 shows that in 2004, the share of basic research in total R&D in China stood at 6.0 percent, one quarter to one-third of the proportions reported by the United States, Japan, and Korea. Moreover, over the past decade, this proportion of basic research to total R&D in China has remained relatively constant in the range of 5–6 percent. Given that in relation to the United States China's GDP is approximately one-sixth, its R&D intensity about one-half, and its proportion of basic R&D spending about one-third, China's total spending on basic research is barely 3 percent that of the United States.

Measures of S&T Achievement

We focus on three measures of S&T achievements. These are patents that have been granted by the United States and Chinese patent offices to the residents of China compared with other nations, publications in international scientific journals, and measures of the relative technological sophistication of China's exports.

Patenting

The first R&D output measure that we use is the number of patent applications filed with the Chinese patent office. Figure 9.2 shows a sharp increase in patent applications, particularly domestic patent applications, from the late 1990s. The figure also shows that invention patents, which are required to meet a higher standard of novelty than utility design and applied patents, rose in the domestic and foreign sectors at comparable rates from 1999 to 2006.

Insert Figure 9.2 here

Table 9.3 shows a profile 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, while significantly less than those of any of the OECD countries and Taiwan, was in 2005 more than India and Brazil while growing faster than any of the countries shown in the list given in Table 9.3. This measure of innovativeness, a measure of the rents that producers can capture from their R&D spending, lags substantially behind measures of S&T effort, namely, R&D spending and the number of scientists and engineers. Whereas China has more scientists and engineers than all countries but the United States, the relative productivity of these technical personnel in producing internationally patentable innovations remains low.

Insert Table 9.3 here

International Scientific Publications

China's share of international publications rose rapidly during the recent decade, from a rank of seventeenth in 1993 to fifth in 2004 (ISTIC, 2005). In 2003, China accounted for over 5 percent of the world's scientific publications. Papers with authors affiliated with Chinese institutions now account for 10 percent of the literature in materials science and 8 percent in mathematics and physics, while China remains one of the smaller players in the life sciences.[14] In terms of citations received by Chinese publications, China's relative ranking is low, just fourteenth in 2004 (Zhou and Leydesdorff, 2006). Papers in many fields, including physics, chemistry, and geosciences, still have “low average impact factors.” Like high-quality patents, China’s incidence of scientific publications and citations has yet to measure up to the sheer volume of the country’s S&T effort.

Export Quality

Data compiled by the World Bank and reported in Table 9.4 show 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, show that for broad groupings of countries the share of high-tech products in total manufactured exports rises monotonically with income per capita; nevertheless, the specific country data show substantial variation within income groupings. Table 9.4 shows that China (23 percent) compares favorably with India (5 percent), Brazil (19 percent), and Japan (24 percent), but trails the United States (24 percent), Korea (32 percent), Thailand (51 percent), and Mexico (84 percent).

Insert Table 9.4 here

Of greater significance from a dynamic perspective is the rapid growth of the high-tech share of China’s exports from about 6 percent in 1990 to 23 percent in 2002. Moreover, while in 1995, foreign-funded enterprises (FFEs) 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, the share that originated from domestically owned firms rose to about 50 percent (Walsh, 2003, pp. 4–5).

From another perspective, Schott (2004) assesses the relative sophistication of China's exports in terms of the degree of overlap between Chinese exports to the United States and those originating from the OECD countries other than the United States. Table 9.5 shows a rapid rate in the measure of overlap, having grown over the recent 30 years, from just 9 percent in 1972 to 75 percent in 2001. Moreover, Schott reports that the extent of China's OECD overlap exceeds that of the other Asian economies and Latin America.

Insert Table 9.5 here

Overall, indicators show that China's S&T intensity is rising rapidly.[15] This rising S&T intensity, however, has not yet propelled China into the upper ranks of innovating countries, as measured by basic research and high-quality invention patent production. This relative paucity of basic R&D combined with the rarity of high-quality patents suggests that the vast proportion of China's S&T resources are focusing on technology transfer and process innovation. As suggested by the rising quality of China's exports, this focus seems to be enabling Chinese producers to match the quality and production efficiency of an increasingly large proportion of goods that are found on world export markets.

Regional Distribution of S&T Effort

While the previous discussion treats China as an integrated, homogenous economy, it is clear that China's level of technology development varies strikingly across regions. The 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 9.6 shows that while covering less than 15 percent of China's population and just 30 percent of its GDP in 2002, these four subjurisdictions accounted for 45 percent of the nation's total R&D spending. That is, on a per capita basis, the R&D intensity of these four provinces/metropolitan areas is approximately three times that of the remainder of the country. Much of the story of China's R&D intensification is centered on the rapidly rising R&D activity of these four most technologically advanced centers.

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For some perspective on the geographic concentration of China's R&D activity, we note that R&D spending in China is more concentrated than that in the United States. While Massachusetts, Michigan, and California, the states with the highest R&D intensity, account for 17.8 percent of the U.S. population, their combined R&D spending amounts to 35.2 percent of total U.S. spending. In China, Beijing, Shanghai, Tianjin, Guangdong, Jiangsu, and Liaoning account for an equivalent 17.8 percent share of China's population, whereas the combined R&D spending of these regions account for 53.6 percent of the national total (Jefferson, 2006).

Several authors have also documented the skewedness of S&T outputs across China's provinces. Research by Wei (2004), and Jefferson and Zhong (2004) shows that the distribution of S&T outputs – patenting and new product development – is highly correlated with the distribution of R&D expenditure across China's regions.

4. THE SHIFTING LOCUS OF R&D ACTIVITY

As a developing country, China's shift toward the consumption and production of goods and services with comparatively high-technology content is expanding S&T roles for the business sector and research institutes as they seek to exploit the returns provided by the growing demand for new technologies. 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 official supervision. These shifts from low income to the living standards of a newly industrializing country and from central plan to market economy are rapidly altering the loci of R&D activity and the incentive structure of China's innovation system.

The Enterprise Sector

Table 9.7 shows the shift in the sectoral distribution of R&D from 1995 to 2005. While Table 9.7 does not report the enterprise share of R&D spending in 1995, the numbers indicate that in 1995, the enterprise share could not have exceeded 45.9

percent. These numbers point to a dramatic increase in the enterprise share of national R&D spending between 1995 and 2000, which was also a period of rapid restructuring in China's enterprise sector. This rapid rise in the enterprise sector's share of R&D spending is also accompanied by a rapid rise in the proportion of enterprise R&D undertaken by nonstate enterprises. By 2005, among China's industrial large and medium enterprises (LMEs), the nonstate enterprise share of enterprise sector's R&D had risen to 74 percent (NBS/MOST, 2006, pp. 219–220 .

Insert Table 9.7 here

Table 9.8 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 rising rates of participation in R&D activity by China's industrial LMEs during 1995-2002, when R&D performers as a proportion of all LMEs rose from 20.2 percent to 31.5 percent, a rise of more than one-half. Over the same period, firms that had been R&D performers in 1995 intensified their R&D operations. The proportion of high-performing LMEs with ratios of R&D to sales ratios in excess of 4 percent grew from 6.4 percent to 14.7 percent in 2002. 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. One conclusion that we draw from Table 9.8 is that the rise in the enterprise sector's share of total R&D spending did not result from a reduction in R&D performance or spending by the other sectors – government, research institutes, or universities – but rather the rapid rise in the enterprise share of R&D spending rose as a result of the rapid increase in the sheer volume of enterprise spending on R&D activity.

Insert Table 9.8 here

The Research Institutes

In 2002, China reported on the activities of 4,347 research institutes. Of these, 744 were directly supervised by the central government, including the 98 institutes that comprise the CAS. More than one-half of the Chinese government's S&T funding is channeled to the 744 research institutes that it directly supervises (NBS/MOST, 2006, pp. 6, 30).

With 11.6 percent of the R&D budgets of these research institutes dedicated to basic research – compared with 5.0 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 directly under the control of the central government that account for 96 percent of the basic research in the government research institute sector (NBS/MOST, 2003, p. 31).

Beginning in the late 1990s, China's government initiated a substantial restructuring of its research institutes, involving efforts to place them on an independent financial footing. In 2004, the Ministry of Science and Technology (MOST) reported that 1,214 of the 5,573 government research institutes that were in operation in 1999 had been restructured. Among the restructuring outcomes, conversion to S&T enterprises (*kejixing qiye*) accounted for 90 percent. In addition, 371 institutes were merged, acquired, or liquidated. Most had been incorporated into enterprise groups, while a small number were incorporated into universities.

Jefferson et al. (2006) find significant economies of scale in their sample of research institutes.[16] The finding that a multitude of relatively small research units have the potential to increase efficiency by combining into larger organizations suggests the importance of the government's restructuring program, in which institutes have the authority to negotiate mergers and acquisitions that can result in efficiency-enhancing economies of scope and scale.

Universities

In 2003, China reported the operation of 1,552 institutes of higher learning, representing about a 50 percent increase from 1995. In the aggregate, higher education accounted for 17.3 percent of the nation's total R&D personnel, somewhat below the 1995 figure of 19.2 percent. Over the same period, the higher-education sector's share of total R&D expenditure fell from 12.1 percent in 1995 to 10.5 percent in 2003. While the sector's share of both total R&D personnel and total R&D spending fell during 1995–2003, its share of basic research rose from 36 percent in 1995 to 37.5 percent in 2003.[17]

Overall, we find in China, particularly during the past decade, the emergence of a more vigorous research establishment – enterprises, independent research organizations, and universities – which are largely self-financed. By 2004, government provided slightly less than 30 percent of total R&D financing, while the contribution of the nongovernmental sector had grown to more than 60 percent.

5. CONTRIBUTIONS OF THE FOREIGN SECTOR: DIRECT AND INDIRECT

Much of the literature on China's S&T system divides over the importance of the foreign sectors in driving China's technological advance. Some accounts emphasize the contributions of foreign businesses to promoting the expansion of productivity and capabilities among domestic firms (Walsh, 2003; Chapter 15 in this volume). Gilboy (2004) takes a decidedly 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 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).

We focus on three dimensions of the role of the foreign sector in driving China's R&D intensification and S&T performance: foreign-funded R&D, FDI, and imported technology.

Role of Foreign-Funded R&D

To test Gilboy's proposition 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 FFE sector, for which we use the definition employed by the National Bureau of Statistics that includes both foreign firms and firms with 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.[18] Moreover, as shown in Table 9.9, in 2001, while the ratio of R&D to value added in China's domestic LMEs had reached 3.29 percent, for the foreign firms it stood at just 2.63 percent. This finding is broadly consistent with a recent OECD report that states, "[F]oreign 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). The imbalance shown in Table 9.9 appears to persist. In 2005, while R&D expenditure as a percentage of *total sales revenue* for China's domestic-funded LMEs stood at 0.8 percent, that for the FFEs and enterprises with funds from Hong Kong, Macao, and Taiwan reported ratios of 0.6 and 0.5 percent, respectively (MOST, 2006, pp. 113, 115). In conclusion, at least in terms of China's surging R&D intensity, during 1995–2005, the direct contribution of China's domestic enterprise sector has outpaced that of the foreign sector.

Insert Table 9.9 here

Role of FDI

China has emerged as the leading recipient of FDI, although on a per capita basis, FDI flows to China are comparable to those of countries in Southeast Asia and substantially less than that of the United States. FDI is likely to motivate R&D effort through two channels. First, concentrations of FDI create technological opportunities for domestic firms, as they can use research funds to imitate products and processes that enter their geographic and technological space. Furthermore, infusions of FDI create competition; simply to survive, domestic firms are obliged to upgrade technologically, so that their product quality and production efficiency enable them to remain competitive.

To test the hypothesis that industry FDI concentration motivates R&D intensity, Gong and Jefferson (2007**)** examine the impact of horizontal FDI (i.e., investment in the same three-digit industry group and the same province) on R&D intensity. They find that foreign-funded FDI (excluding that from Hong Kong, Macao, and Taiwan) interacts with domestic in-house R&D to motivate greater levels of R&D intensity.

In their study of the determinants of patent applications filed with China's State Intellectual Property Office (SIPO), Hu and Jefferson (2006) find a surprising result: even after controlling for R&D expenditure and ownership type, concentrations of FDI within the same three-digit standard industrial classification (SIC) industry group substantially increase the firm's propensity to patent. When they subdivide their sample into domestic and foreign firms, they find that while this result is extremely robust for domestic firms, it is insignificant for patenting by foreign-owned companies. The result seems to indicate that access to enlarged technological opportunity afforded by proximity to kindred FDI substantially expands patenting opportunities for Chinese firms. The robust association between FDI and domestic company patenting may also reveal a pattern of strategic patenting, in which domestic firms use the patenting system to lodge law suits, secure settlements, or simply to force delay to weaken competitor company claims to intellectual property rights. Whether the motivation is to exploit new technological opportunity or to infringe on the intellectual property of competitors, Hu and Jefferson (2006) show that industry FDI is an important driver of domestic firm patenting.

Role of Imported Technology Markets

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” (2004, 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. Except for their parent companies from whom they transfer technology, the FIEs are substantially less connected with local technology markets than their domestic counterparts.

Table 9.10 shows the importance of technology purchases in relation to overall S&T spending with China’s industrial LMEs. As a proportion of total internal S&T expenditure, the purchase of imported technology, nearly 30 percent in 2000, stood at 27.6 percent in 2003, having grown at an annual rate of 18.0 percent during 2000–2003. At just 3.7 percent of total internal S&T expenditure in 2003, the purchase of domestic technology played a much smaller role; however, with purchases having doubled over the period 2000–2003, it represents a growing share of total internal S&T spending.

Insert Table 9.10 here

Firms that purchase imported technology invariably support in-house R&D operations. In-house R&D shows strong complementarities with technology imports, enabling domestic firms to capture higher returns to their own R&D spending.[19] Our research also finds that domestic firms that combine in-house R&D with imported technology are more likely to be active exporters.[20] 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, 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. Such affiliates with major R&D activities include Dupont, Ford, GE, GM, IBM, Intel, Lucent Technologies, Microsoft, and Motorola. According to Moris (2004), during 1997–2000, the R&D/VA ratio of these firms rose from 1.1 percent in 1997 to 9.2 percent in 2000. 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 possibly the impact of the government's "technology for markets" policy. In addition, a number of these foreign affiliates with substantial R&D operations have established R&D alliances with Chinese counterparts. Referencing the Thomas Financial Joint Ventures Alliances database, Moris reports that from 1990 to 2001, U.S. and Chinese-owned companies and other organizations formed 105 new business alliances with large R&D components, substantially more than the 78 alliances that U.S. companies formed with Japanese, German, British, Singapore, and Canadian companies during the same period.

Summarizing, we find that FIEs are not leading the intensification of China's R&D effort. However, the foreign sector does play a key role in motivating rising R&D intensity through at least two indirect channels. One is FDI that motivates domestic R&D spending and patenting; the second is through technology markets that interact with imported R&D to enhance the innovative efficiency in China's domestic enterprise sector. While the R&D affiliates of multinational firms do indeed exhibit high levels of R&D intensity, the total volume of their research activity remains a small percentage of China's total R&D spending.

6. OVERNMENT POLICIES AND PROGRAMS IN SUPPORT OF S&T

China's government is committed to advancing China rapidly to the ranks of the world's leading innovators. The Tenth Five-Year Plan sets 2015 as the target for China's emergence as a leading innovation economy. Here, we review the essential government components of China's public S&T system. These include its organization, specific government programs that provide R&D financing, and incentives for private innovation.

Organization

Three key organizations administer most civilian science and engineering research in China, although the Ministries of Defense, Health, and Agriculture, the State Forestry Administration, and other economic agencies also have significant research operations under their direct management. The Ministry of Education oversees and funds all universities in the country.

The MOST provides policy guidance on the S&T system reform agenda and formulates policies on how to strengthen basic and applied research and technology development, especially in the high-tech area. Recently, MOST has focused on S&T development strategies that complement the nation's economic reform and development agenda. The ministry provides funds for S&T programs in both basic and applied research, for instance, the high-technology R&D program commonly referred to as the "973 Program." MOST also collects a range of statistical data relating to China's S&T system and publishes annually *China's Science and Technology Yearbook*, in collaboration with the NBS, and publishes biannually the *China Science and Technology Indicators*, which reviews the state of China's S&T system

The *National Natural Science Foundation of China* (NSFC) was consciously modeled after the National Science Foundation of the United States, when it was established in 1986 with the mandate to "encourage innovation and to fund excellent and creative research through fair competition on the basis of scientific and democratic principles ….” NSFC funds peer-reviewed basic and applied research in the natural sciences, that is, physics, mathematics, and chemical and life sciences. As such, China's NSFC incorporates the functions and resources that in the United States would be assigned to the National Institutes of Health. Within these functional areas, peer review panels recommend awards. Principal grant awardees are Chinese universities and CAS research institutes.[21]

The *CAS* operates on two levels. Elected academy members have a significant consulting and advisory role. More substantively, however, CAS loosely manages close to 100 independent research institutes, which conduct scientific research in all branches of the natural sciences. Each institute's funding is an amalgam of resources from CAS Headquarters, MOST, and the NSFC. . In addition, institutes earn varying amounts of money from owning and operating spin-off enterprises. CAS Headquarters also owns spin-offs. The Chinese Academy of Engineering was formed more recently and is a much smaller organization than CAS, playing only a consulting and advisory role, with no research institutes, graduate school, or research centers, such as those in CAS.

Government 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 9.11 summarizes their key features. The programs that focus on basic research include the "Key Projects Program" (*Gongguan*), the "863 Program" (*Baliusan*), and the "973 Program" (*Jiuqisan*). Programs that focus on diffusion include the "Torch Program" (*Huoju*), which focuses on the commercialization and dissemination of new technologies in industry, and the "Spark Program" (*Xinghuo*), which is focused on the development of S&T in rural areas.

Insert Table 9.11 here

Focusing on basic research, the "863" and "973" programs are largely funded by the state and mostly performed by universities and research institutes. We are not aware of any systematic studies in the public domain that evaluate the effectiveness of these programs. Indirect and anecdotal evidence suggests that they have been productive. For example, in 2002 these programs together accounted for 408 invention patents, or 7 percent of all the invention patents granted to domestic inventors in China.

The other three programs – the *Key Projects,* the *Torch*, and the *Spark* programs deal mostly with the "D" or the development and diffusion stage of innovation. The Key Projects Program is a top-down program, 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 nationwide establishment of S&T parks to encourage the formation of high-technology start-ups. Instead of grants, government support is limited to preferential tax treatment within the parks. Perhaps in part to compensate for risk taking by the enterprises, the government has allowed for a greater role of nonstate ownership in these parks, which increases the private returns that 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. With the majority of financing coming from self-raised funds and bank lending, it is the entrepreneurs who decide which technologies to adopt.[22]

Both the Torch and the Spark programs have been successful. Walcott (2003**)** provides rich institutional details of China's S&T parks established under the Torch Program. Hu (2007) 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) document the multidimensional success of the program. For example, they report that in 1995 TVEs 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.[23]

Incentives for the Enterprise Sector

In China, the central government also stimulates R&D through the provision of grants and tax incentives to the enterprise sector. China's large- and medium-size 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 1998–2004, R&D grants as a proportion of R&D spending by LMEs fell by two-thirds, while the proportion of tax subsidies rose by approximately 40 percent. These proportional changes suggest two observations. First, government support for R&D in the enterprise sector has shifted from direct grants toward indirect subsidies. Second, the decline in grant support indicates that the abrupt increase in the enterprise sector's R&D spending has not been driven by government funding.

In addition, the national *Torch Program* provides a range of public services to high-tech enterprises, notably, in technology development zones, including incubators and educational services. Furthermore, companies that are certified as new/high-tech enterprises become eligible for a range of tax subsidies, including a two-year income tax exemption and lesser continuing tax reductions thereafter.[24]

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 the scope of patent protection. The impact of stronger patent protection is clearly reflected in the annual patent grants plotted in Figure 9.3. The number of patents granted rose sharply in 1993. The temporary fall back in 1994 was followed by the persistent and rapid growth of patenting, particularly during 1997–2002 when total patent grants increased at an average annual rate of 21 percent.

Insert Figure 9.3 here

Figure 9.3 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.[25] The contrasting performance of domestic and foreign inventors exhibited in Figure 9.3 further corroborates the hypothesis of an increasingly robust patent system. In 2003, over 300,000 patent applications were submitted. This number, however, includes "utility model" and design patents, which are relatively modest adaptations of existing technologies. If we limit our scope to the 105,318 applications for new inventions, we find that almost half (48,549) were from foreigners and over half (56,769) were from Chinese citizens. Clearly, the patent system is beginning to play a role in the strategies of foreign companies in China, which increasingly seek to protect intellectual property whatever the source. At the same time, Chinese inventors are finding it worthwhile to begin protecting their own intellectual property.

Technology Standards

China's effort to promote indigenously developed technologies as industry standards has received wide attention.[26] Suttmeier and Yao (2004) interpret these developments through the lens of "neo-techno-nationalism," that is, the pursuit of national interest by establishing national technology standards that give advantage to Chinese suppliers. In the face of an avalanche of foreign technologies that result in substantial payments from Chinese (and other) users, a central objective of China's government is to encourage and enable Chinese industry to develop intellectual property that will reverse the flow of rents in favor of Chinese firms. An important part of this strategy is for the government to organize technology standards, indeed a technology architecture that will provide Chinese innovators with an advantageous environment in which to achieve these technology goals.

The greatest attention has been given to the Chinese government's efforts to promote standards for third-generation (3G) mobile telephone technology and the Time Division Synchronous Code Division Multiple Access (TD-SCDMA) standards**.** China also continues to develop an alternative to the Windows operating system by promoting Linux systems. Finally, the introduction of a new security standard for wireless devices, the WLAN Authentication and Privacy Infrastructure standard (WAPI), has received international attention. In addition, Suttmeier and Yao (2004) identify several areas in which efforts are under way to promote standards. These include the following:

- China’s own microprocessor (the “Dragon chip”);
- China’s own successor to DVDs (the “EVD” – Enhanced Versatility Disc) standard;
- A new digital audio standard (AVS – Audio, Video, Coding Standard);
- A Chinese standard (IGRS – Intelligent Grouping and Resources Sharing) for communicating among digital devices;
- A new Internet protocol (IPV6); and
- Radio frequency identification tagging (RFID). </BL>

China’s focus on promoting technology standards that apply to the information technology industry is not a matter of coincidence. The actual and potential size of the Chinese market for information products raises the stakes for standard setting in China. 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 United States 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 the anticipated growth of the Chinese market to influence technology standard setting to the benefit of Chinese firms.

However, another element of the government's S&T development strategy may work against the process of establishing independent technology standards, that is, the government's emphasis on establishing channels for international cooperation. According to a recent publication of the MOST,[27] China is a member of more than 1,000 international cooperation organizations. China's government has established S&T cooperation ties with 152 counties and regions and signed intergovernmental cooperation accords with 96 countries. Under one of these accords, China and the United States established in 2005 the China-U.S. Nanotechnology Institute, involving collaboration between Zhejiang University and the U.S. California Nano-System Institute. The goal of the accord is to "set a role model for S&T system reform in Zhejiang province … and the whole country." As of September 2005, approximately

160 Chinese universities and research institutes had established S&T collaboration with EU counterparts, involving EU investments of 418 million euros.

Thus, we observe two opposing forces that impinge on the motive for China to set national technology standards: efforts to create a technology framework that will enable Chinese firms to develop new technologies that generate IPR rents formerly ceded to foreign firms along with the desire to maintain an open collaborative technology playing field, so that China can access, adopt, and possibly improve upon the latest technologies, using already-established foreign technology standards.

CASE STUDIES

This section presents case studies that focus on two industries – semiconductors, including elements of the electronics industry, and automobiles, pillar industries that the Chinese government has targeted for rapid development through its industrial and S&T policies. The case studies summarize the state of technology in each industry in relation to the international frontier, the strategic issues for catch-up, and the role of policy in facilitating or hindering technological advance.

Semiconductors

China's emerging semiconductor industry constitutes an important backward linkage to China's electronics industry, which is rapidly growing in both the volume and the range of electronic consumer goods and industrial equipment.

State of the Technology

China's first S&T plan, formulated in 1956, selected electronics technology, including semiconductors, as one of the twelve targeted areas for intensive government support (Yuan et al., 1992). Chinese scientists developed the silicon digital integrated circuit in 1965 – seven years after Robert Noyce and Jack Kilby invented the integrated circuit – placing China within reasonable reach of U.S. leadership in semiconductor technology. However, the disruption caused by the Cultural Revolution and the parallel explosive growth of semiconductor technology left China far behind by the late 1970s. In China's second major S&T planning exercise in 1978, electronic computing was again selected as one of the eight major target areas for state support (Yuan et al., 1992).

A most remarkable example of technological catch-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, increased from 6 to 39 percent. During this period, U.S. and Japanese shares declined from 47 and 31 percent to 19 and 23 percent, respectively.[28] Korea is now the world leader in DRAM (Dynamic

Random Access Memory) manufacturing, whereas Taiwan hosts the world's largest semiconductor foundries. Will China be the next to leapfrog to the world's semiconductor technology frontier?

Strategic Issues for Catch-up

A confluence of events has contributed to the rapid rise 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 FDI, particularly Taiwanese investment, which has contributed investment, technology, and human talent. 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.

When China started to rebuild its semiconductor industry in the early to mid-1980s, 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 0.35–0.5 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.

Establishing 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, more recently, foreign wholly owned semiconductor firms, particularly Taiwanese companies, have built new production facilities. Of the twenty-one semiconductor-manufacturing plants operating as of 2003 or expected to operate in 2004 in China, nine were built after 2001 and four are 100 percent owned by foreign investors (Howell et al., 2003, figure 10). 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 technology, thereby placing China among the world's top semiconductor makers (*Reuters News*, September 25, 2004).

C-Head Role of Policy

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 (VAT) rebate that applies to semiconductors produced within China. China levies a VAT 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 by the manufacturing cost advantage. China has agreed to phase out the tax subsidy in compliance with WTO requirements.[29]

In addition, integrated circuit (IC) manufacturers can receive a five-year corporate income tax holiday. 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 nineteen 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 seven such start-ups 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 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 rapid technological progress, the semiconductor industry perhaps represents one of China's best hopes of leapfrogging to the world technology frontier.

Automobile Industry

While China built its first automobile plant in 1953, only in recent years has consumer demand begun to emerge to support a domestic automotive industry with the potential to operate at with the scale economies needed for efficient automotive production.

State of Technological Development

When China began opening its economy three decades ago, its automotive industry lagged woefully behind that of the world's major automobile producers. China's first automobile plant, First Automotive Works, located at Changchun in Northeastern

China, manufactured the *Jiefang* (Liberation) trucks, using technology transferred from the Soviet Union. Dissatisfaction with the slow progress of China's indigenous automotive industry, which lacked the technological capability to design and manufacture high-quality vehicles, encouraged China's government to open the domestic market to foreign investment while also requiring that foreign companies team up with local companies to make cars.

Representing perhaps the beginning of its modern automobile industry, China's first automobile joint venture, Beijing Jeep Corporation (BJC), was established in 1983 between Beijing Automobile Industry Corporation, owned by the Beijing municipal government, and American Motors Corporation (AMC), which was later acquired by Chrysler, which later merged with Daimler-Benz in 1999. BJC produced two models, BJ212, a technology transferred from the Soviet Union in the 1950s, and Jeep Cherokee XJ. It took Chrysler eighteen years to introduce its second model, the Grand Cherokee, to the joint venture in 2001. When Volkswagen formed the joint venture with Shanghai Automobile Industry Corporation in 1985, it produced a model, Santana, which was no longer produced anywhere else (Gallagher, 2003).

Fast forward to March 2006, when Honda prepared to introduce its latest version of the Civic in China just months after it went on sale in Europe, Japan, and the United States, andToyota was already assembling its Prius gasoline–electric hybrid car in China, the only country outside Japan where the car is produced. Ford just opened a second production line in China that is almost identical to one of its most advanced factories in southwestern Germany (Bradsher, 2006).

Notwithstanding allegations of intellectual property rights violation, the Chinese indigenous automobile makers have emerged from anonymity and irrelevance to become significant market players. In January 2006, they accounted for 28.7 percent of the domestic Chinese market, followed by Japanese (27.8), European (19 percent), American (14 percent), and Korean brands (10.3 percent). This was the first time Chinese indigenous brands had leapt ahead of foreign brands in China (Bradsher, 2006).

In 2005, China became the world's second largest automobile market after the United States, with sales of 5.92 million units. A development that went relatively uncelebrated occurred in 2005 when China became a net vehicle exporter for the first time, exporting 172, 800 units, up 120 percent from a year earlier (*Reuters News*, February 10, 2006), although in dollar terms export volume trailed imports by a ratio of one to three, 15.95 billion and 59.53 billion dollars, respectively.

Strategic Issues for Catch-up

China's enormous market potential has convinced every major international automobile manufacturer to enter the Chinese market by setting up a joint venture with a local Chinese partner as required by the Chinese government. The early entrants' faith in the Chinese automobile market has paid off with the explosive growth of automobile sales since the beginning of the century. In the process, the Chinese government has leveraged the potential of the Chinese market by extracting technology transfer from foreign investors through the requirements of local content and domestic majority ownership.

In addition, the Chinese government also protected the domestic automobile industry through high tariff and nontariff barriers. These policies have arguably generated mixed or even dubious results and have been inconsistent over time. China's entry into WTO forced the Chinese government to eliminate or significantly curtail its protective policies. Ironically, entry into WTO has not weakened China's automobile industry as many in China had feared. In fact, FDI, technology transfer, and the growth of indigenous Chinese automobile manufacturers all accelerated after China's entry into WTO; the automobile industry grew by 60–70 percent each year from 2001 to 2004. Greater competition in the industry as a result of China's entry into WTO is the most likely explanation. We further examine three of these factors later.

Foreign automobile manufacturers have accelerated entry and investment in China and have transferred ever advanced and new models to the Chinese market. Foreign investment totaled 880 million dollars in the 1980s. However, foreign investment into the automobile and related industries reached 60 billion dollars in the 1990s (Gallagher, 2003), a figure that is likely to have been exceeded during the first five years following China's entry into WTO in 2001.[30]

With surging investment from all major international automobile manufacturers, the Chinese automobile industry is becoming increasingly competitive. The top ten passenger-car manufacturers in China by sales in 2005 are Shanghai-GM, Shanghai-VW, First Auto Works (FAW)-VW, Beijing Hyundai, Guangzhou-Honda, FAW-Xiali, Chery, Dongfeng-Nissan, Geely, and Dongfeng-Citroen. Together they accounted for 73 percent of total car sales (NBS, 2006). Chery and Geely are two indigenous Chinese firms with their own brands. Shanghai-VW for the first time lost its number one spot to Shanghai-GM. While Volkswagen, Shanghai-VW, and FAW-VW had captured 60 percent of the Chinese market in the mid-1990s, as a result of the rapid entry of foreign competitors and technology transfer to domestic manufacturers, notably, Chery and Geely, by 2005 VW's market share had dropped to just 17.3 percent.

The Role of Policy

In 1994, a decade after the first automobile joint venture was established, the Chinese government formulated its explicit industry policy for the automobile sector. The policy has three major components. First, the policy aimed to consolidate the dozens of automobile makers to achieve economies of scale. At the time, no automobile manufacturers were able to reach the minimum efficient scale of 150,000 cars per year for chassis and power train manufacturing. The government was targeting the creation of a "Big Three, Mini Three" mix of automobile manufacturers. Second, tariff barriers were created to protect the domestic automobile manufacturers from foreign import competition. Tariffs in 1994 were 110–150 percent for finished vehicles. There were also import quotas. Lastly, as a way to extract technology transfer, all foreign automobile manufacturers were required to form joint ventures with local partners in which foreign ownership was limited to 50 percent. All these joint ventures were also required to source at least 40 percent of their parts and components locally. The foreign joint ventures were encouraged to set up technical centers to train Chinese engineers, technicians, and workers.

China's first automobile industry policy largely failed to achieve its objectives. At the turn of the century, the automobile industry remained fragmented, causing production to be well below the efficient scale. During the same period, there had been limited technology transfer from foreign automobile makers.[31]

The National Development and Reform Commission issued a new automobile industry policy in 2004.[32] Entry into WTO required China to adopt a number of liberalizing measures with respect to the automobile industry. These include reducing import tariffs for complete vehicles and automobile parts to 25 percent and 10 percent, respectively, by July 1, 2006; gradually phasing out import quotas and licenses by 2005; and eliminating requirements for technology transfer and localization. With the exception of firms operating in the special economic zones, foreign ownership was still limited to 50 percent.[33] Under the new policy, new automobile-manufacturing projects have to make an initial investment of at least 2 billion yuan. The 2004 policy also adopted an explicit objective of encouraging indigenous research and development. Finally, the policy also emphasized the development of a secondhand car market, car financing, and a network of car dealers.

Following China's entry into WTO, growing market competition and declining import restrictions caused automobile prices to fall – the price of a VW Santana fell from 120,000 yuan (14,500 dollars) in 2001 to 80,000 yuan (9,700 dollars) in 2003 (Goldman, 2003) – while also prompting foreign automobile makers to introduce more and newer models to the Chinese market. Greater competition and falling prices have spurred a new wave of foreign investment rather than discouraging it. Instead of stifling the indigenous car-manufacturing industry, China's own automobile manufacturers and their brands have never been stronger; three Chinese automobile makers, Shanghai Automotive Industry Corporation, Chery, and Geely, have announced plans to sell low-cost cars to the U.S. and European markets (*Reuters News*, April 24, 2006).

Problems persist in the industry. The president of China's Chang'an Motors complains that while the Chinese "authorities will encourage the development of low-emission vehicles, such as compact cars our company produces .... [M]any cities are implementing discriminatory measures against mini vehicles, prohibiting them from driving on main avenues. That is a problem that the new policy has no means of addressing, and that will require stronger regulations to resolve."[34]

A second issue facing the industry is intellectual property disputes. Japanese motor companies, such as Toyota, Honda, and Nissan, have acted as plaintiffs in intellectual property rights (IPR) lawsuits against China's young automobile makers. A number of Chinese automobile makers – Geely, Chery, Lifan, Shuanghuan, and Great Wall Motors – which have their own brand cars stand accused of copyright infringement, patent right infringement, and unfair competition. Honda has brought two actions against China's largest private motorcycle manufacturer – Chongqing Lifan Industrial Group – in Beijing and Shanghai.

Besides Japanese automobile companies, General Motors (GM) denounced Chery's QQ mini car for copying its own Chevrolet Spark. GM claimed that both the QQ and the Spark are based on the Matiz of South Korea's Daewoo Motor, which has been already acquired by GM. The Spark is produced at GM's joint venture in South China's Guangxi Zhuang Autonomous Region. GM China Group said that it had completed its investigation of Chery's alleged piracy. But Chery Automobile Company announced that Chery itself had developed the QQ mini cars, having already acquired the relevant patent rights. Chery deniede violating the IPR rights of other automobile makers. The Ministry of Commerce invited GM representatives and officials from relevant Chinese departments late last year for discussions on how to solve the dispute between GM and Chery. But no result was ever reported.

Among the rising number of IPR lawsuits and disputes between foreign and domestic automobile makers, the only judgment so far was made in November 2003 in the lawsuit put forward by Toyota against Chinese automobile maker Geely for trademark infringement and unfair competition. Geely won the case, which was the first ever foreign-related motor lawsuit after China's entry into the WTO. The Beijing No. 2 Intermediate People's Court rejected Toyota's claim, which sought compensation of 14 million yuan (1.7 million U.S. dollars) from Geely – one of China's major economy car producers based in Zhejiang. Toyota claimed that the logo of Geely is similar to that of Toyota, resulting in trademark infringement and unfair competition. Toyota also charged that Geely advertising intentionally misled consumers by suggesting that Geely had close relations with the Japanese brand. After losing the case, sources within the court said that Toyota accepted the judgment rather than appealing to a higher court..[35] While Chinese automobile companies have yet to lose to a foreign plaintiff in a Chinese court, once China begins exporting its cars to the U.S., EU, and Japanese markets, so that foreign automobile makers acquire standing in their home courts, foreign IPR claims may be more rigorously enforced.

7. 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 several 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 9.12, we summarize the results of a number of studies that have investigated the impact of R&D on a range of performance measures. These include cost, productivity, profitability, and new product development. All show robust returns to R&D. We review these studies later.

Insert Table 9.12 here

Hu and Jefferson (2004a)

Using a panel of approximately 1,000 industrial LME enterprises for 1991–1997 from the Beijing region, the authors estimate 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 Lin (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 impact of innovation inputs on domestic patent applications. With either fixed or random effects, the authors find that expansion of either S&T expenditure or S&T personnel results in a significant expansion of patent applications.

Jefferson, Bai, Guan, and Yu (2004)

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. The key statistical relationships are surprisingly robust, including the contributions of R&D expenditure to new product innovation, productivity, and profitability. 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 times 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. State-owned enterprises, while extremely inefficient at creating new knowledge, appear to put new knowledge to good advantage. This result may reflect the monopoly power of some SOEs (e.g., in the tobacco industry). In addition, their relative initial inefficiency may allow SOEs to attain large efficiency improvements from small restructuring efforts.

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 R&D personnel with a large number of firm- and metropolitan-specific characteristics, the authors identify a substantial list of factors that effectively complement the firms' basic R&D operations: these 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, Jefferson, and Qian (2005) use a panel of approximately 10,000 industrial LMEs from 1995 to 2001 to estimate the direct and interactive impacts of R&D spending and the purchase of both domestic and imported technology. The 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, such as chemical, pharmaceutical, machinery, and electronics, 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. FDI, 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 (2006) .

This paper employs a panel of approximately 1,500 energy-intensive industrial LMEs over the period 1997–2001. They use a translog cost function and fixed effects estimator to assess both the neutral and the 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. Additionally, 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. Fisher-Vanden and Jefferson 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.

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, Jefferson and Qian (2005) find strong complementarity of internal R&D and imported technology; this complementarity is stronger for domestic firms than for FIEs.

- Fisher-Vanden and Jefferson (2004) find that in-house R&D focuses primarily on process innovation; imported R&D focuses more on product innovation.

The Factor Bias of R&D

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 4 percent of China's total GDP.[36] The story of China's technological transformation is far more subtle than the development and export of high-tech goods.

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, heavy machinery, and 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 saving.[37] 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 – that is, 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, are 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 reorientation – 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.[38]

8. HOW SUSTAINABLE IS THE GROWTH OF CHINA'S S&T ACTIVITY?

Has China begun its S&T takeoff? From 0.6 percent in 1996, China's statistics show its R&D intensity accelerating rapidly to 1.4 percent in 2006. At 1.4 percent, China's R&D intensity is more than one-half that of the United States and substantially greater than what should be expected given the country's level of per capita income.[39] This acceleration raises two questions: what is driving China's R&D intensification? Has China begun its S&T takeoff?

The endogenous growth literature is one useful starting point for understanding the factors that are contributing to the intensification of China's R&D effort. These are the following[40]:

- The rising relative share of R&D spending on products embodying labor-intensive versus technology-intensive intermediate inputs, including capital goods.
- Rising R&D productivity spurred by the growth of complements.

- Scale economies in innovation as expansion of the underlying body of knowledge creates opportunities for new innovation.
- Effective subsidies to R&D.

We focus on the role of each of these four factors:

– *Shifting consumption and production patterns*. As living standards rise, the composition of goods and services shifts from products with low-technology content to goods and services that are more technology 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 nonagricultural goods greater than 1, but also goods with low-technology content (e.g., bicycles, handicrafts, and rudimentary medical care) become inferior goods. Conversely, the income elasticity of demand for high-technology goods is high.

Within China, electronics and telecommunications illustrate China's emerging high-tech sectors. Table 9.13, which features three of these industries, shows that, during the latter half of the 1990s, the ratio of R&D spending to value added among large- and medium-sized firms in the electronic and telecommunication sectors accelerated by 250 percent to reach nearly 7.5 percent. The overall impact on Chinese industry of growing R&D intensity was magnified by the doubling of this sector's share in total industry sales over this period. The table also demonstrates the same association between rising R&D intensity and growing market share for China's electrical equipment and machinery industry and the instrumentation sector. While some portion of this relative growth in the production share of high-tech products is driven by changes in patterns of domestic consumption, the growth of export demand also contributed to rising production of technology-intensive goods.

Insert Table 9.13 here

– *Rising productivity of R&D personnel*. As part of a World Bank study on innovation in East Asian cities, Jefferson and Zhong (2004) compare 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 9.14, based on surveys of 300 firms in each of the six cities, summarizes differences reported by the firms in each of the cities with respect to openness, human capital resources, R&D networking, and institutional quality. 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 returns to R&D.

Insert Table 9.14 here

We conclude that the availability of complements to R&D – graduate training in science and engineering, experience abroad, investment in IT equipment and technology parks, and technology networking – is an important driver of the productivity of R&D personnel. Moreover, in China the rate of increase in these complements is motivating a rapid rise in R&D productivity measured in terms of the marginal revenue product per R&D worker.

– *Rapidly expanding knowledge base rich with new technological opportunity*. In a small closed economy, it is reasonable to expect that rising R&D intensity might encounter diminishing returns to R&D. Without the replenishment of technological opportunity from a large and diversified industrial base or the inflow of new technologies from abroad, innovation possibilities are likely to fade. Among the world's developing economies, China may be unique. The size and openness of China's economy, including the intensity of trade, volume of FDI inflow, and rapidly growing markets in domestic and imported technologies continuously replenish the opportunities for new technological innovation. The impact of China's inflow of FDI on technology development has been documented by Hu and Jefferson (2006), who show the robust impact of FDI on domestic patenting and by Girma, Gong, and Gorg (2005), who show the impact of FDI on the rate of new product innovation. In China, the scale of technology transfer and the opportunity to move up the technology ladder are combining to offset tendencies to diminishing returns to R&D.

– *Subsidies to R&D labor*. Perhaps the finding of greatest interest is the large margin between the cost of R&D personnel and the returns to R&D personnel in Chinese cities compared with international standards, as represented by Seoul. This result suggests that foreign firms can raise their returns to R&D by outsourcing portions of their R&D operations to China rather than Seoul (or other overseas locations).

Specifically, as shown in Table 9.14, we have used the World Bank database to estimate the average returns to R&D personnel in five Chinese cities and also to calculate the average cost of an R&D worker. As shown in Table 9.14, in 2000 an investor in R&D who spent 20,847 U.S. dollars to hire one worker in Seoul could expect a return of 37,639 dollars. In Shanghai, the same amount could hire in nearly four R&D workers who together would generate nearly 100,000 dollars in revenue. Given the rapid increase in the productivity of the R&D sector and the rate of increase in the training of new young S&T graduates, Chinese R&D personnel, at least in the early part of the decade, seem to have offered a bargain. While compensation paid to China’s R&D personnel has risen rapidly, it appears that R&D productivity has risen faster.</UL></BL>

Why So Early?

We speculate on possible reasons why China displays signs of an apparent S&T takeoff at an unusually low level of per capita income.

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 percent) and Turkey (15.4 percent) with substantially higher incomes, and well below that of India (43.5 percent).[41] 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. The paucity of installed infrastructure for earlier-generation technologies, such as land telephone lines, early vintages of automobile assembly lines, and early computing technologies, both hardware and software, opens the door for the rapid dissemination and adoption of new vintages of technologies. Certain key sectors, such as telecommunications, exhibit a substantial degree of technology leapfrogging.[42]

Market Size

The rise of living standards in some countries leads to more extensive imports of technologically sophisticated electronic and telecommunications equipment and other high-tech goods, including electrical machinery, instrumentation, and automobiles. In China, multinationals are clamoring to set up production for these R&D-intensive industries in proximity to China's burgeoning consumer markets. This commercial desire to produce in proximity to large markets may explain why S&T takeoff has not occurred in certain smaller OECD countries (e.g., Norway, Australia, Belgium, and New Zealand) while, with the exception of Italy, it has occurred in all the largest OECD economies.[43] Through its "markets for technology" strategy, China's government has been able to leverage the size of its markets to push international firms toward accelerating the shift of design, R&D, and component production toward China. Commenting on the decision by airbus to assemble its A320 plan in China, one analyst was quoted, “Everything else being equal, you would never choose to put a production line in China” (Landler and Bradsher, 2006).

Proximity to Dynamic Economies

Arguably, China’s greatest asset in making its transition from plan to market and accessing the capital, technology, and talent needed to move along the trajectory from low- to middle-income economy is its physical and cultural proximity to Hong Kong and Taiwan and to a lesser, but still significant, degree to Korea, Japan, and Southeast Asia. One measure of this importance is that approximately one-half of the accumulated FDI in China has originated with Hong Kong, Taiwan, and Macao. Another is the concentration of FDI in specific regions within China, including Taiwanese investment in Dongguan (Guangdong Province), which has become the primary source of many PC components. Singaporean investment in the Shanghai area and Korean investment in China’s northeast region have also spurred technological advance. This proximity has at once served as a channel for technology transfer and access to the human capital that can use it not only within the foreign sector but also within China’s domestic sector through joint ventures, licensing, and contracting.

The four factors associated with the endogenous growth process have been central to the intensification of R&D across all countries that have achieved S&T takeoff. But not all emerging economies have experienced S&T takeoff. We suggest that China's high literacy rates, perceived potential, and proximity to dynamic economies have driven China's S&T takeoff along an earlier and steeper trajectory than would have been the case without these particular characteristics. If China follows historical statistical patterns, we should expect the continuation of growth of R&D expenditure to outpace GDP growth until R&D intensity levels out in the 2–3 percent range.

9. CONCLUSIONS AND DISCUSSION

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, including the proximity of certain coastal areas to Hong Kong, Taiwan, and OECD trade and FDI flows, have created an unusually high degree of technological diversity within China's borders. This diversity will continue to 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 international technological frontier of certain industries, the country's huge pool of surplus labor will generally 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 research we review shows that as China moves away from its tradition of central planning with an emphasis on capital-intensive heavy industry, many of its R&D resources are being used to develop ways of adapting and utilizing foreign technologies to a more labor-intensive setting.

The foreign sector is playing a critical role in promoting China's S&T development. Increasingly large numbers of foreign-trained scientists and engineers are returning to China. By expanding technological opportunity, promoting competition, and eroding the rents of established Chinese firms, the flood of FDI is promoting the adoption and intensification of R&D operations in domestic firms. In some industries, such as semiconductors and automobiles, China is rapidly developing its internal R&D capabilities, often in an environment of large inflows of FDI and increasingly competitive international trade, which requires that production, for both domestic and overseas sales, closely approximate established international standards.

China’s S&T development and its ongoing economic restructuring are mutually reinforcing. Many of China’s high-technology companies grew out of murky ownership and property rights arrangements. Continued reform of the governance of China’s enterprise and financial systems is 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 potentially support the effective enforcement of intellectual property rights, which in turn is needed to support new investment, both domestic and foreign, in 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 for 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 its goal of becoming a world technology power. If China succeeds in fortifying its market institutions, including reforming its financial system to allow for more private resources to enter risky ventures and promoting the more rigorous enforcement of intellectual property rights, and continues to promote its openness to foreign technology and investment, its economy is likely over the next 10–15 years to emerge as a global technology power.

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Footnotes

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[2] The data, collected annually by China’s National Bureau of Statistics, provide detailed data by the ownership and industry classifications that have been formulated by the NBS.

[3] For an excellent overview of Needham’s seven volumes of *Science and Civilization in China*, see Goldsmith, (2006).

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[4] Agricultural innovations include the iron-tipped plow, the moldboard, and the seed drill widely used during the Han dynasty. See Lin (1995) for a description of other early Chinese inventions.

[5] See, notably, Sivin (1982).

[6] See Elman (2005).

[7] Among the most notable advocates were Zeng Guofan, a Hunanese scholar-general, and Feng Guifen, who wrote most extensively about the ideals of the Self-Strengthening Movement.

[8] This section borrows from Naughton (2007, chapter 15).

[9] Naughton (2007).

[10] The difference arises from the use of both Cobb Douglas and translog functions, which yielded the lower and higher estimates respectively.

[11] Ministry of Science and Technology annual survey of research institutes, 1995–2003.

[12] *People's Daily Online*, October 16, 2006, http://english.people.com.cn/200610/16/eng20061016_312140.html.

[13] In the data reported in UNDP (2001), China's level is just 0.7 percent. Comparative country data in NBS (2003), however, indicate, however,

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that by 2002 the R&D intensities of other low-middle--income countries had not exceeded 1 percent.

[14] Nature, vol. 431, p. 116 (September 9, 2004), http://www.nature.com/nature/journal/v431/n7005/full/431116b.html.

[15] Some observers question the quality of China’s R&D data, such as that shown in Table 9.1. The provision of tax subsidies for R&D spending, for example, may provide an incentive to Chinese firms to overreport their R&D spending. However, at least until recently, the rates of taxation levied on R&D-related investments have been 33 percent for domestic firms and just 17 percent 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 United States and many European countries, like China, maintain incentives for R&D (see Data Brief, 2001).

[16] This finding is consistent with that of Jin et al. (2003), who in their study of forty-six wheat and maize breeding institutes from 1981 to 2000, found robust economics of scale in China’s crop breeding

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research. According to their findings, the current large number of small crop breeding institutes is the main source of inefficiency.

[17] These ratios are calculated from data reported in NBS/MOST (2004**)**, p. 4, 6, 293.

[18] Chinese statistics classify firms with full or partial foreign investment as "foreign-invested enterprises." In 2001, domestic owners held 61 percent of the overall equity in such firms. We use this share to assign a proportion of FIE 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.

[19] Hu, Jefferson, and Qian (2005) show this result within the context of a production function. Fisher-Vanden and Jefferson find this result using a cost function approach.

[20] Fisher-Vanden and Jefferson (2004).

[21] Executive Summary of China's Science and Technology System and its Impact on the Research Community, An October 2002 Report from U.S. Embassy Beijing, http://www.usembassy-china.org.cn/sandt/ST-ReportSum.htm.

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[22] http://www.chinaconsulatesf.org/eng/kj/kjjh/.

[23] It is unclear that the study takes into account the nonrandomness of participation in the Spark Program. So the evidence presented is only suggestive.

[24] http://us.tom.com/english/446.htm.

[25] 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 United States shown in Table 9.1. Clearly, the economic value of many Chinese patents seeking protection in the United States is not large enough to compensate for the costs involved in obtaining a U.S. patent.

[26] 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).

[27] *China Science and Technology Newsletter*, The Ministry of Science and Technology, People's Republic of China, http://www.most.gov.cn/eng/newsletters/2006/t20060213_28707.html.

[28] See www.sia-online.org.

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

[30] A rough and partial count of foreign investment in the automobile industry includes Volkswagen investing 2 billion dollars in 2002, Ford investing 100 million dollars in 2001, Nissan committed to investing 1 billion dollars in 2002, and Daimler-Chrysler investing 1 billion dollars via Hyundai in 2003, not to mention outlays by GM, Honda, Toyota, Volvo, and many others.

[31] Gallagher documented the failure of foreign manufacturers in transferring current air-pollution-control technology to China.

[32]http://www.china-embassy.org/eng/gyzg/t127767.htm.

[33] Multinationals can still own only half a joint venture. But foreign investors will be allowed to control stakes of more than 50 percent in

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automobile and motorcycle joint ventures (JVs) with Chinese partners "if their joint ventures are built in China's export processing zones and shoot at overseas markets."

[34] Yin Jiaxu, president of Chang'an Motor Corporation, China's biggest mini vehicle maker. The firm jointly produces compact cars with Japan's Suzuki Motors, http://www.chinadaily.com.cn/english/doc/2004–06/09/content_337978.htm.

[35] http://www.sipo.gov.cn/sipo_English/gftx_e/IPR%20Special/t20040906_33373.htm.

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

[37] 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 (2002) find that privatized enterprises invest in labor-using technologies far more than unconverted state-owned enterprises.

[38] A particularly buoyant account of China's move up the technology ladder into foreign export markets is provided by Fishman (2004). A key

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point in that article is the ability of domestic producers to outcompete foreign-invested enterprises by establishing labor-intensive workshops that produce high-end domestic products and export goods of similar quality at lower cost.

[39] 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--2,975 dollars. With a reported level of per capita income of 890 dollars in 2002, China lies toward the bottom of this range.

[40] These factors are motivated by Jones (1995) in an endogenous growth model focusing on the determinants of demand for R&D personnel. Gao and Jefferson (forthcoming) apply the factors to China.

[41] UNDP (2001).

[42] For an account of technology leapfrogging in the Japanese steel industry, see Ruttan (2001, chapter 5).

[43] The desire to serve large and fast-growing consumer markets creates a premium for the establishment of production centers that can benefit

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from learning by doing and learning by using in proximity to burgeoning demand.

Table 9.1. *Comparative Measures of R&D Intensity, 1991–2003*

R&D Expenditure/GDP[1]	1991	1995	2000	2003
China	0.74	0.60	1.00	1.23[b]
USA	2.72	2.51	2.76	2.62
Germany	2.52	2.25	2.49	2.50
Japan	2.93	2.89	2.99	3.12[a]
Korea	1.92	2.50	2.65	2.96
Taiwan	–	1.78	2.05	2.16
France	2.37	2.31	2.18	2.20[a]
Italy	1.23	1.00	1.07	–
Brazil	0.46	0.69	1.05	–
India	0.85[a]	0.77[b]	0.86[a]	–

[a] Indicates data for the previous year.

[b] Indicates data for the following year.

Source: NBS/MOST (2004, p. 385 .

Table 9.2. *Comparative Measures of Innovative Intensity, 2003*

Country	China	USA	Korea	Canada	Turkey
Scientists and engineers per 10,000 population	10	90	62		10
Basic research (% total R&D)	5.0	18.1	12.6		
R&D funds (% enterprise funded)	60.4	68.9	74.9	53.7	33.4

Source: NBS/MOST (2004, p. 386).

Table 9.3. *Patents Granted by the U.S. Patent and Trademark Office, 1991–2003*

	1991	1995	2000	2003
China	50	62	119	297
USA	51,177	55,739	85,068	87,901
Japan	21,025	21,764	31,295	35,517
Korea	405	1,161	3,314	3,944
Taiwan	906	1,620	4,667	5,298
France	3,030	2,821	3,819	3,869
Italy	1,209	1,078	1,714	1,722
India	22	37	131	341
Brazil	62	63	98	130

Source: http://patft1.uspto.gov/netahtml/PTO/srchnum.htm.

Table 9.4. *High-Technology Exports as a Percent of Exports of Manufactures, 2002*

Low-middle income (17%)	China	India	Thailand	Brazil
	23	5	31	19
Upper-middle income (21%)	Malaysia	Hungary	Mexico	Argentina
	58	25	84	7
High income (23%)	USA	Japan	Korea	Taiwan
	32	24	32	42

Source: World Bank (2005, p. 262–263.

Table 9.5. *Percent of China's U.S.-Bound Exports That Overlap with OECD Exports to the United States*[a]

1972	1981	1991	2001
0.09	0.28 (10)	0.55 (4)	0.75 (3)[b]

[a] Manufacturing export similarity indexes with the OECD.

[b] The number in parentheses represents the rank among all non-OECD countries, excluding Korea; after Mexico (0.80) and Korea (0.80).

Source: Schott (2004).

Table 9.6. *Regional Comparisons of R&D Spending, 2002*

	R&D Expenditure	Total (%)
TOTAL	128.8	100.0
Central 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

Note: Values are in billion yuan.

Source: NBS/MOST (2004).

Table 9.7. *Distribution of R&D by Performance (Financing)*[a]

Year	Enterprise	Research Institute	Higher Education	Government	Others
1995	≤45.9	42.0	12.1		
2000	60.0	28.8	8.6		2.7
2003	62.4 (60.1)	25.9	10.5	(29.9)	1.1 (10.0)[b]

[a] Values are in percent.

[b] Comprised of foreign funds (2.0 percent) and other funds (8.0 percent).

Source: NBS/MOST (2004, p. 7).

Table 9.8. *Distribution of Ratio r = R&D/VA among Large and Medium Industrial Enterprises, 1995–2992*

Year	0	$0 < r \leq 1$	$1 < r \leq 2$	$2 < r \leq 4$	$4 < r \leq 6$	$6 < r \leq 10$	$r > 10$
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
2002	68.5	7.5	4.3	5.1	3.2	3.9	7.6
Percentage increase	−11.1 (45.6)	−7.5	22.8	40.8	108.0	110.8	119.1

Note: The figures in parentheses represent the share of total LMEs that fall within each percentile range of R&D/intensity; values are in percent.

Source: NBS-LME data set.

Table 9.9. *Domestic versus Foreign Contributions to R&D Spending in 2001 (Industrial LMEs)*

	Domestic	Foreign/ HKT
1995		
Firm count	16,823	1,323
R&D exp (RMB1,000s)	67,130	6,480
R&D/value added (%)	1.11	0.99
2001		
Firm count	14,429	4,360
R&D exp (RMB1,000s)	281,770	53,380
R&D/value added (%)	3.29	2.63
2001:1995		
R&D exp (RMB1,000s)	4.19	8.23
R&D/value added (%)	2.96	2.66

Source: NBS-LME data set (2001).

Table 9.10. *LME Spending in Technology Markets*

	2000	2003	Annual Growth (%)
Internal S&T expenditure	82.4	146.8	21.2
Purchase of imported technology	24.5 (29.7%)	40.5 (27.6%)	18.2
Purchase of domestic technology	2.6 (3.2%)	5.4 (3.7%)	27.6

Note: Values are in billion yuan; figure in parentheses is proportion of total internal S&T expenditures.

Table 9.11. *Major National Science and Technology Programs*

Program	Year Started	Focus and Objective
Key Technologies R&D Program	1982	Aims to solve the key and comprehensive problems concerning national economic and social development; covering agriculture, electronic information, energy resources, transportation, materials, resources exploration, environmental protection, medical and health care, and other fields. Investing the most funds and employing the most personnel, this program was the largest S&T program in China in the twentieth century
National High-Tech R&D Program ("863" Program)	1986	The "863" Program includes twenty themes, such as biotech, space flight, information, laser, automation, energy, and new material. The research agenda of the program is decided by panels of scientists, who are responsible for closely monitoring developments in international scientific research so as to set research goals and programs that warrant government support. Its results are intended to be quickly deployed to industry
National Program on Key Basic Research Projects ("973" Program)	1997	Like "863," "973" focuses on enabling China's S&T capabilities to catch up with those of the OECD countries. However, it intends to focus on those issues that challenge China's economic and social development in the twenty-first century. These include basic research with a multidisciplinary approach in fields such as agriculture, energy,

		information, environment of resources, population and health, and materials
Torch	1988	Focuses on the commercialization of new technologies, developing high-tech products that meet international technology standards, and establishing high-tech development zones across China, including the nurturing of entrepreneurship through incubators and science parks
Spark	1986	Aims to revitalize the rural economy through S&T and to popularize science in rural areas. As of 2004, there were more than 100,000 scientific and technological demonstration projects being carried out in 85% of rural areas across China

Source: http://www.china.org.cn/english/features/China2004/107131.htm.

Table 9.12. *Returns to R&D*

Study	Data	Functional Form; Estimation Method	Key Findings
Hu and Jefferson (2004a)		Production function; OLS	A positive elasticity of TFP w.r.t. R&D personnel
Cheung and Lin (2004)	Provincial-level data		A positive elasticity of patent production w.r.t. S&T personnel
Jefferson et al. (2006)	5,451 LMEs	Production function Instrumental variables (IV)	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 (2004)	1,800 surveyed firms in five 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, Jefferson, and Qian (2005)		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 (2004)	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

Table 9.13. *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
Electronic and telecommunication equipment	2.97	7.34	2.49	1.91
Electronic equipment 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

Note: VA, value added.

Source: Jefferson, Bai, Guan, and Yu (2006).

Table 9.14. *Comparison of Seoul and Five Chinese Cities*

City	Composite Index of R&D Capabilities	Estimated Returns to R&D Personnel (dollars) (1)	R&D Personnel Wage (dollars) (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).

Figure Captions

Figure 9.1. Research and Development Expenditure in Five Economies, 1950–2004 (*Source*: Gao and Jefferson, 2007)

Figure 9.2. Number of Patent Applications Received by China SIPO (*Source*: Hu and Jefferson, 2006.)

Figure 9.3. Number of Patents Granted by China SIPO (*Source*: Hu and Jefferson, 2006.)