China’s Path to Indigenous Innovation

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Note: Chinese names are written with the family names last.

1. Productive Capabilities and Economic Growth in China

In 2006 the Chinese government made the promotion of indigenous innovation[1] central to its Medium- and Long-Term Plan for the Development of Science and Technology (2006-2020) (Liu et al. 2011). We define "indigenous innovation" as the process within a developing nation of improving the quality and lowering the cost of world-leading technologies that had previously been transferred from abroad. For any developing country, indigenous innovation is essential to enter into global competition in industries that rely on sophisticated technologies. As has most dramatically been demonstrated by the experiences of Japan, South Korea, and Taiwan, indigenous innovation ultimately provides the foundation for attaining and sustaining a high standard of living (see Lazonick 2004).

Over the past decade, increasingly driven by indigenous innovation, China has emerged as the new global economic power. In this paper we examine China's record in indigenous innovation and how it has been achieved. An understanding of China's path to indigenous innovation is important to a) China, b) developing economies, and c) advanced economies.

China: Once we have a sound analysis of the drivers of China's path to indigenous innovation, we can ask whether indigenous innovation has provided and will continue to provide the foundations for economic growth in China that is equitable and stable – or what Lazonick (2009a) has called "sustainable prosperity". Through the globalization process, Chinese economic growth, especially in the ICT industries, is linked to the stock-market oriented "New Economy business model" (NEBM) which, in the United States, has been a source of considerable inequity in the distribution of income and instability in employment (Lazonick 2009a and 2009b). If Chinese policy-makers want to avoid the pitfalls of NEBM, they will need to know how to structure the "risk-reward nexus" in the innovation process to ensure that indigenous innovation indeed contributes to sustainable prosperity (see Lazonick and Mazzucato 2012).

Developing economies: China is the latest of a series of Asian nations to follow a dynamic growth path that has pulled hundreds of millions of people out of poverty. Those who are concerned about raising standards of living in the poorer nations of the world need to know what is unique about China's path, and what new insights can be gained by placing the Chinese experience in cross-national historical perspective. Like all nations, including an advanced economy such as the United States, China's growth is the result of the interaction of the "developmental state" and the "innovative enterprise" (Lazonick 2011). Developing nations can learn from China what type of interaction might work for them. More than that, at this particular historical conjuncture, given the size, rate of growth, and productive power of China, any developing nation that seeks to embark on a path to indigenous innovation needs to understand the opportunities and challenges of doing so in the presence of China as a major economic power with growing export capabilities and burgeoning domestic markets.

Advanced economies: As through indigenous innovation, China moves into the production of higher valued-added goods and services, the advanced nations of the world need to know how to respond to the Chinese challenge. It has become common for analysts and policy-

[1] Zi Zhu Chuang Xin (自主创新) in Chinese.

makers in the advanced nations to view trade rule violations, currency manipulation, and unfair subsidies as the prime sources of China's competitive advantage. The implication is that limiting these practices, insofar as they exist, will level the playing field between China and the advanced economies. If, however, indigenous innovation is the prime source of China's competitive advantage, then the challenge for the advanced economies is how to remain innovative themselves. In the case of the United States, it can be argued that major US corporations that are making ample profits in China are failing to reinvest them to upgrade innovative capabilities in the United States (Milberg and Winkler 2010; Lazonick 2012a).

The framework that we use to analyze China's path to indigenous innovation considers the dynamic interaction among a) investments in physical and human (particularly science and technology) infrastructures, mostly undertaken by the state; b) technology transfer from the more advanced nations, especially via foreign direct investment and the return migration of Chinese-born scientists, engineers, and entrepreneurs educated and trained in the advanced nations; and c) the formation and growth of indigenous companies that can improve upon technologies both developed by China's S&T infrastructure and transferred from abroad (see Lazonick 2009a, ch. 5).

Conceptually, the analysis of China's path to indigenous innovation draws upon "the theory of innovative enterprise" with its focus on the dynamic interaction of "strategic control", "financial commitment", and "organizational integration" in the growth of the firm (Lazonick 2010b). By innovative enterprise, we mean a business concern that, through the development and utilization of productive resources, seeks to generate higher quality, lower cost products than had previously been available. Strategic control concerns the abilities and incentives of those business executives who decide how to allocate a firm's resources to investments in innovation. Financial commitment concerns the firm's sources of investment capital that can sustain the innovation process from the time when money is committed to it until the time when financial returns are available. Organizational integration concerns the incentives that a business enterprise provides to people in the hierarchical and functional division of labor to contribute their skill and effort to the collective and cumulative learning process that is the essence of innovative enterprise.

In the next section of this paper, we illustrate investments in physical and human infrastructures that form the essential foundation of China's path to indigenous innovation. In the following section, we discuss the main modes of technology transfer – joint ventures with foreign multinationals and experienced high-tech returnees – that have charted the path. Then in the fourth section, we provide evidence on the attainment of indigenous innovation in the computer, communications technology, automobile, and semiconductor industries. Finally we sketch out the implications of our inherently historical approach to understanding China's path to indigenous innovation for a "catching up with history" research agenda that seeks to monitor and analyze the evolution of this path as it unfolds in real time.

2. Infrastructure Investment

Economic growth requires investment in infrastructure, defined as productive resources that are available for use by a multitude of business enterprises and that are not produced for the use of a specific business enterprise. Physical infrastructure includes "public goods" such as roads, airports, telecommunications systems, post offices, hospitals, and schools as well as basic inputs into the production process such as steel and energy. In a developing nation most of these investments are made through agents of the government, i.e., government ministries or state-owned enterprises. Human infrastructure includes "public services" such as research institutes, schooling at different levels, health services, police forces, fire brigades, and postal services. Infrastructure is essential for the economy to function. Infrastructure also tends to be high fixed cost, requiring large initial investments and long durations from the time at which these investments are made until the time that they are fully utilized as inputs into the production process. The high cost of infrastructure investment and its status as a public good or service mean that households and businesses look to governments to undertake these investments.

a) Investment in physical infrastructure

In the 1980s China planned, operated and regulated its infrastructure investments through an array of government ministries. Over this period of time, the investments in physical infrastructure remained modest. The combined investment in three main categories of infrastructure – transportation, telecommunications and electricity – accounted for less than five percent of GDP throughout the 1980s. In particular, annual investment in telecommunications infrastructure averaged a meager 0.2 percent of GDP.

In 1993 the Chinese government restructured its ministries, forming state-owned enterprises (SOEs) to take over the roles of investing in and operating critical types of infrastructure.[2] The Chinese government granted these SOEs the ability to borrow investment funds from the State banking sector. The result was a surge in investment in infrastructure. From 1993 the combined annual rate of growth of investment in transportation, telecommunications and electricity was regularly above six percent of GDP, and during the 2000s this rate of growth was frequently above eight percent of GDP (Naughton 2007, 345; China Statistics Year Book 2000, 2005, 2010, section 16).

As an example of investment in a basic industrial input, let us look at the case of steel. In 1979 China accounted for 4.6 percent of world crude steel production compared with 16.6 percent for the United States and 15.0 percent for Japan. China surpassed the United States in steel production in 1993 and Japan in 1996. In 2011 China's crude steel production was 6.8 times its level 15 years earlier, and represented 45.9 percent of the world total, compared with Japan 7.2 percent, United States 5.8 percent, India 4.8 percent, Russia 4.6 percent, and South Korea 4.6 percent.[3] With the exception of Jiangsu Shagang Group, a township and

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[2] For a recent review of SOEs in China, see Szamosszegi and Kyle (2011).

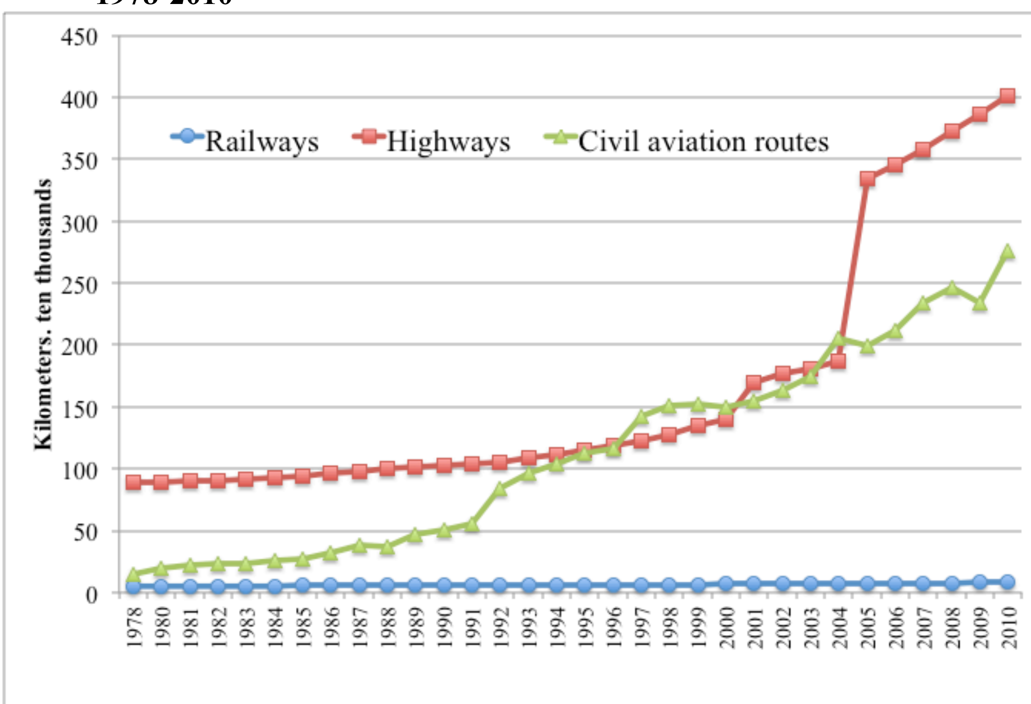
[3] These data are from the World Steel Association, Steel, Statistical Yearbook, various years, available at http://www.worldsteel.org/statistics/statistics-archive/yearbook-archive.html. For the 2011 data, see

village enterprise (TVE) founded in 1975 that was privatized in 2001, all of the major companies in the Chinese steel industry are SOEs (see Tang 2010).

The primary sources of demand for steel have been urbanization, building and infrastructure construction in China. Over the past decade, China's steel industry ha been able to support the surging growth of the automobile industry. A recent report from Credit Suisse (Deverall et al. 2012) estimates that demand for steel from the transportation sector accounts for 20 percent of overall steel production in China, second only to its use in construction.

As we discuss below, China has emerged as the world leader in motor vehicle production, measured in the number of units produced. But cars and trucks need roads. Figure 1 shows the relation between the expansion of China's system of railways, highways, and airways. In the 1990s and 2000s China invested in its railway system, increasing kilometers in operation by 58 percent from 1990 to 2010 with the proportion of the system consisting of national electrified railways increasing from 12 percent to 36 percent. Nevertheless, as can be seen in Figure 1, the major focus of building the transportation network was in highways and airways, with a huge road-building boom occurring the 2000s.

Figure 1. Expansion of China's system of railways, highways, and airways, 1978-2010

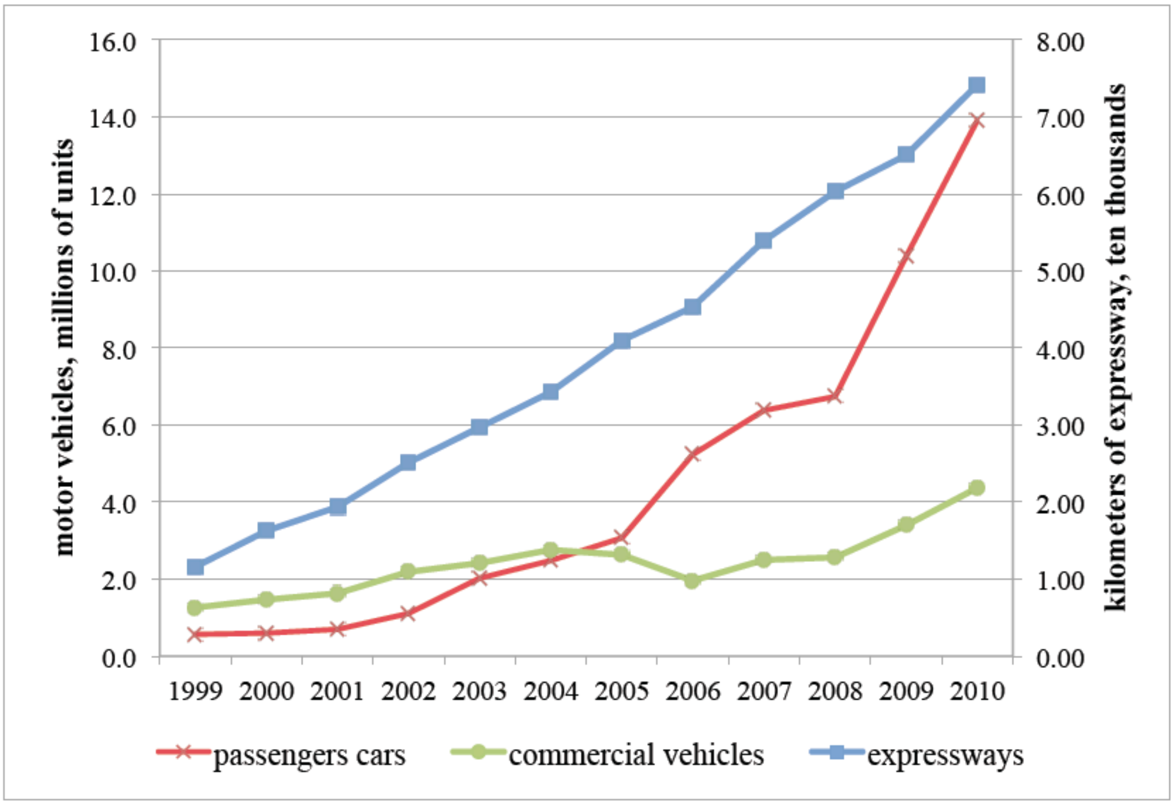


Source: *China Statistics Year Book* 2011, table 16-4, plus previous issues.

As illustrated in Figure 2, the building of highways was largely in anticipation of the boom in automobile production in China, almost all of which continues to be for sale on domestic markets. Begun in 1990, China's National Trunk Highway System (NTHS) seeks to build

http://www.worldsteel.org/dms/internetDocumentList/steel-stats/2011/Crude-steel-production-2011/document/2011%20steel%20updated%20Feb2012.pdf about 35,000 kilometers of expressway by 2020, encompassing "five vertical and "seven horizontal" national trunk highways (Li and Shum 2001). Under the pressure of urbanization, in 2004 the Chinese government launched the National Expressway Network (NEN), also called the "7-9-18" Highway Network (Scharenbroich et al. 2008). By 2011 NEN had reached 65,000 kilometers, making it the second largest expressway system in the world, next only to the United States.[4]

Figure 2. Expressways in operation and annual motor vehicle production in China, 1999-2010



Sources: China Statistical Yearbook, 2011, table 16-4; "Production Statistics" at International Organization of Motor Vehicle Manufacturers website, http://oica.net/category/production-statistics/

Investment in human infrastructure

The Communist regime of China emphasized education since the early days. From 1952 to 1978, China spent approximately 2 percent of the GDP on education except for the years of the Cultural Revolution (1966-1976) (Yao 2009). That was a considerable commitment for a very poor country. By the time of reform, China had already built up foundations of mass education. The 1982 census showed that 66.5 percent of the adult population had received some formal schooling. By comparison, in India that figure was only 27.5 percent. Chinese higher education, in contrast, remained underdeveloped, with only 0.9 of the population receiving any college education in 1982 (Barro and Lee 2000).

[4] "Tolls Roads in China," *BRIC Spotlight*, Thomas White Global Investing, 2010.

Table 1 shows the extent to which from 1960 to 2010 China invested in its education system compared with a number of other advanced and developing economies. In 2010, only 4.0 percent of the Chinese population, 25 years and older, had completed a higher education degree. Given the size of its population, however, in 2010 the number of Chinese who had competed post-secondary education amounted to about 35 million people, up from about 21 million in 2000 and 26 million in 2005. One way at looking at the post-secondary schooling completion rate in China is that the nation has had phenomenal growth for three decades, but, as yet, has barely tapped the advanced education potential of its population. Average years of schooling among this population (25 years and over) have also increased substantially. Among the population 15 years and older, the average years of schooling were 8.2 years, up from 7.1 years in 2000 (Barro and Lee 2010). There is little doubt that these levels of educational attainment in China will climb rapidly over the next two decades or so.

Table 1. Post-secondary school completion rates and average years of schooling, 1960, 1980, 2000, and 2010, selected nations

Country	**Completed post-secondary**				**Average years of school**			
% pop., 25yrs.+	1960	1980	2000	2010	1960	1980	2000	2010
USA	9.4	18.1	30.6	31.6	8.9	11.9	13.0	13.3
Japan	3.0	8.9	19.0	23.9	7.2	8.9	10.7	11.5
Hong Kong	3.1	4.1	7.2	7.2	4.4	6.7	8.7	10.0
Singapore	0.9	2.1	7.8	12.3	2.8	3.7	7.6	8.8
South Korea	1.9	6.6	14.8	17.3	3.2	7.3	10.6	11.6
Taiwan	2.4	4.7	8.0	10.6	4.6	6.4	9.6	11.0
Indonesia	0.1	0.3	1.7	1.6	1.1	3.1	4.8	5.8
Malaysia	0.7	0.5	3.1	5.0	2.3	4.4	8.2	9.5
Philippines	4.5	9.8	19.8	22.4	3.7	6.1	8.0	8.7
Thailand	0.4	2.9	5.1	8.9	3.4	3.7	5.4	6.6
Brazil	1.1	3.7	5.3	5.2	1.8	2.6	5.6	7.2
Mexico	1.1	3.9	10.2	13.9	2.6	4.0	7.4	8.5
Chile	1.8	3.3	9.5	11.6	5.0	6.4	8.8	9.7
Costa Rica	2.1	5.2	12.9	13.2	3.7	5.4	8.0	8.4
China	0.4	0.6	2.8	4.0	1.4	3.7	6.6	7.5
India	0.4	1.5	3.2	3.7	0.9	1.9	3.6	4.4

Source: Barro and Lee 2010

The comparison of educational attainment between China and India is instructive. In 2000 a higher percentage of the population, 25 years and older, had completed post-secondary education in India than in China, but the average years of schooling were higher in China. While India's emergence as a global competitor has been focused mainly on information technology services, China's development path has been much more diverse. In entering a full range of industries with different levels of skill, China has had the advantage over India of a much more extensive system of mass education, as shown in Table 2. In both countries, higher education is still for an elite, however large numerically, and in 2010 China had surpassed India in the proportion of the population who had completed higher education. At the other end of the education spectrum, the proportion of the population with no schooling has declined to low levels in China compared with India.

The Chinese government has emphasized basic education by requiring nine years of education for the whole population. By 2004 the average years of schooling of the population reached eight. Chinese colleges and universities expanded dramatically in the early 2000s, with the number of college graduates rising from one million in 2001 to over three million in 2004 and five million in 2008 (China Statistics Year Book 2010, table 20-9).

Table 2. Highest levels of educational attainment of the populations, 25 years old and over, China and India, 1980, 2000, and 2010

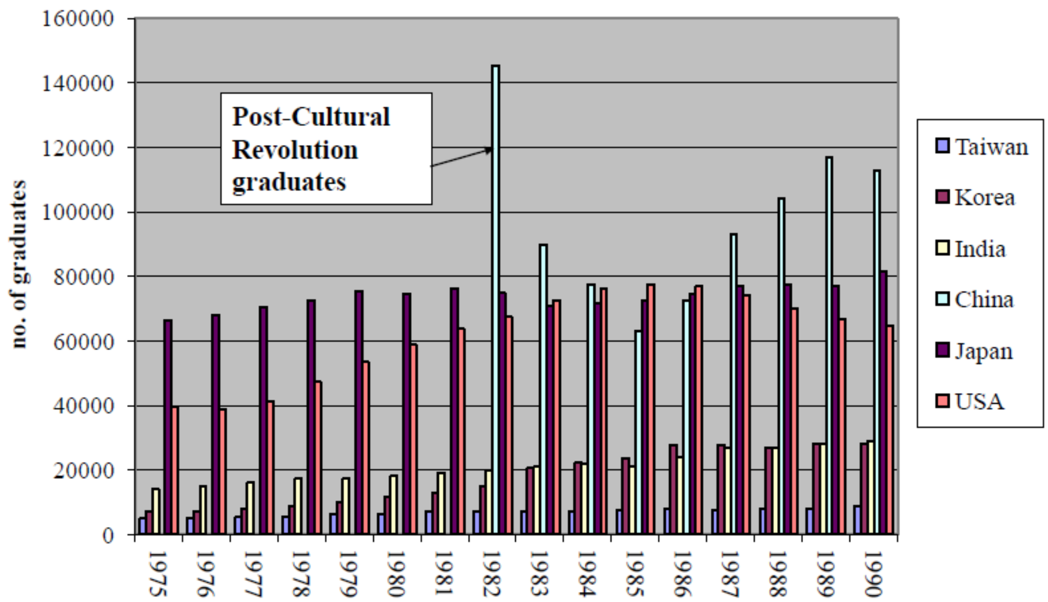
	China			India		
Highest level of educational attainment (% who completed level in parentheses)	1980	2000	2010	1980	2000	2010
No schooling	36.0	13.5	8.2	72.5	51.2	42.2
1st level (primary education)	41.3 (17.5)	34.3 (19.8)	29.2 (17.7)	11.3 (4.9)	18.4 (14.2)	19.1 (16.6)
2nd level (secondary education)	21.7 (5.6)	48 (28.5)	56.5 (40.2)	13.7 (0.4)	25.5 (0.7)	32.8 (1.0)
Post-secondary (higher education)	1.0 (0.6)	4.3 (2.8)	6.2 (4.0)	2.5 (1.5)	4.9 (3.2)	5.9 (3.7)
Average years of school	3.7	6.6	7.5	1.9	3.6	4.4

Source: Barro and Lee 2010.

At the university level, as shown in Figures 3 and 4, an important difference between China and India in the 1980s was that China emphasized undergraduate degrees in engineering while India emphasized undergraduate degrees in science. In terms of the supply of college-educated personnel, therefore, China was much better positioned than India in the 1990s to absorb technology from the advanced nations and adapt it to indigenous industrial uses.

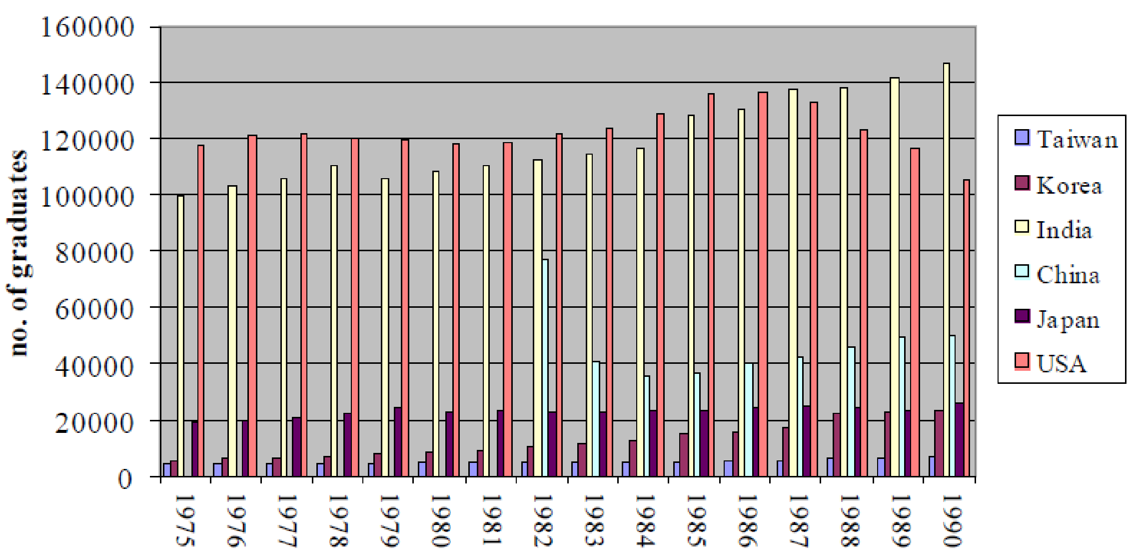
The formation of China's current S&T infrastructure can be traced back to the 1950s (Simon 1989). Long-term planning for S&T development was first instituted during the National Conference on Science and Technology held in 1956. To serve the Communist Party's ambitions for heavy industrialization and defense modernization, a small, elite research system was set up in the 1950s, led by compatriot scientists, and focused on research related to chemistry, machinery, medicine, automobiles, among other areas. On the eve of the Cultural Revolution, China has approximately 120,000 R&D personnel working in a research system comprised of the Chinese Academy of Sciences, industrial ministries, and the universities. This S&T system could claim considerable achievement, such as the development of an atomic bomb and the launching of satellites.

Figure 3. Bachelor's degrees in engineering, selected Asian countries and USA, 1975-1990



Source: National Science Foundation 1993

Figure 4. Bachelor's degrees in natural sciences, selected Asian countries and USA, 1975-1990



Source: National Science Foundation 1993

During the 1980s, the reform of the S&T infrastructure included the establishment of a variety of government R&D programs. The Key Technologies R&D Program launched in 1982 aimed at making breakthroughs in technologies that were viewed as key to the development of the economy. The implementation of this program was on a four-year cycle so that its foci could evolve with the changing needs of the economy. The Spark Program, launched in 1986, sought to encourage technological change in the rural economy, particularly through the promotion of Town and Village Enterprises (TVEs) that would make use of science and technology. The High-Tech Research and Development Program, also known as the 863 Program, begun in 1987 on the recommendation of a group of renowned Chinese scientists, identified key technology areas in which China could potentially make breakthroughs, focusing particularly on catching up with the developed nations. The Torch Program, launched in 1988, promoted the development of high-tech industries, with a specific focus on providing the legal and organizational frameworks for the creation and growth of high-tech industrial development zones.

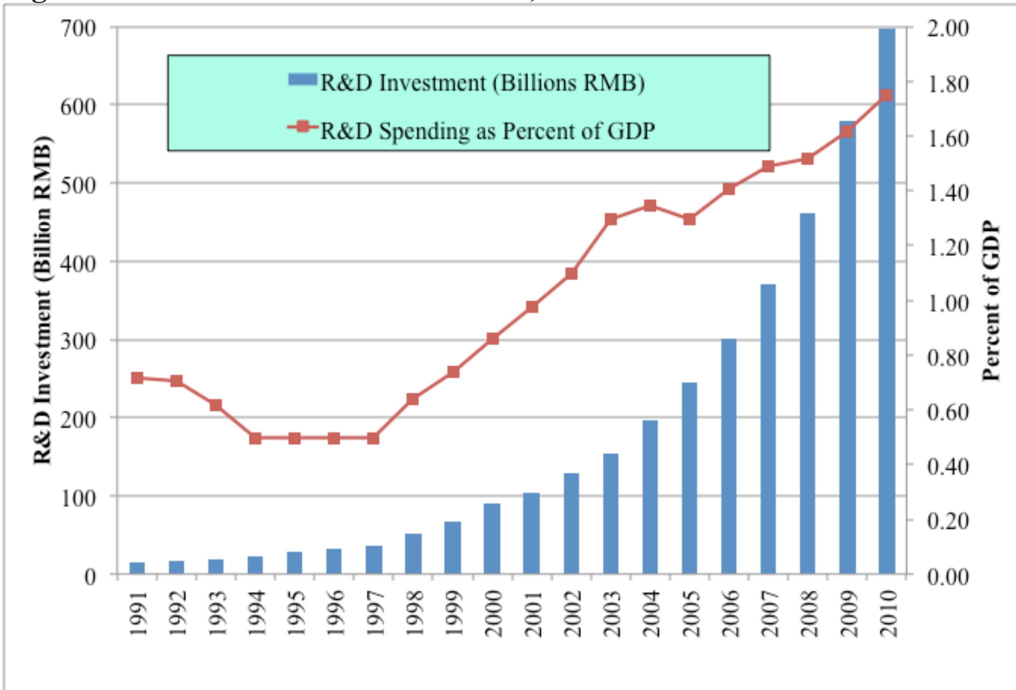
In the context of this expanding S&T system, the government permitted public research organizations, including state labs and universities, to experiment with institutional reforms, including spin-offs of business enterprises. The success of some of the spin-off technology companies, such as Legend (later known as Lenovo) and Founder, encouraged the government to incorporate large public R&D institutions as part of large business enterprises. For example, Legend took over the running of the Institute of Computing Technology of the CAS in 1995, approximately ten years after the company was spun out from the Institute. The transformation of research institutes in applied research into business enterprises gave rise to a growing share of R&D funded and performed outside the direct control of the Chinese State. By the late 1990 business enterprises accounted for more than half of China's R&D spending (China S&T Statistics Year Book, various years).

Despite the launch of these various government R&D programs during the 1980s, China's R&D expenditure as a proportion of GDP actually declined, falling from 1.2 percent in the mid-1980s to less than 0.8 percent throughout the 1990s. But the passage of the Science and Technology Progress Law in 1993 and the campaign for "revitalizing the nation through science and education" (kejiao xingguo) that began in 1995 marked further commitments of the government to building China's S&T capability. The National Key Basic Research Program, or 973 Program, launched in 1997, reorganized the various overlapping State programs and increased funding to basic research. The Chinese Academy of Science (CAS) began to restructure itself in 1998 through the CAS Knowledge Innovation Program. In 1999 the government set up the Innovation Fund for Technology-based Small- and Medium-sized Enterprises to award grants to start-up technology companies.

As a result of these various initiatives, as shown in Figure 5, China's R&D intensity rose steadily as a proportion of GDP from a low of 0.5 percent of GDP in 1997 to 1.35 percent in 2004 and 1.80 percent in 2010. Figure 6 shows the huge increase in investment in R&D personnel in the 2000s, driven by the allocation of people to "experimental development" research, indicating an increasingly important role for the innovative enterprise in developing basic and applied research, most of which is carried out by government entities, to the point where new knowledge can be embodied in commercial products.[5]

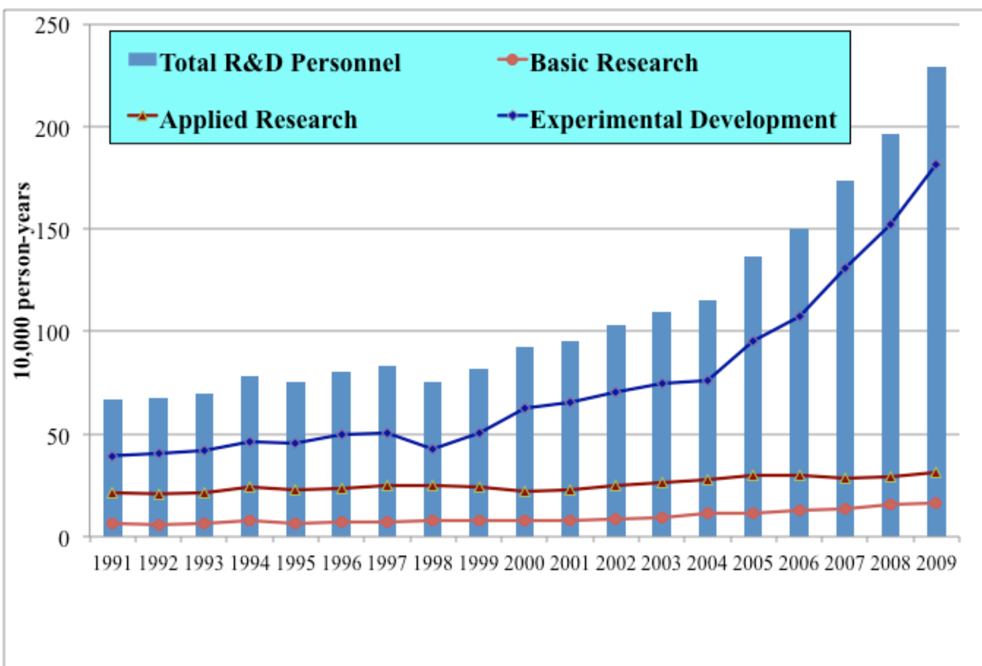
[5] According to the National Science Foundation (2012, 4-53), "The OECD notes that in measuring R&D, the greatest source of error often is the difficulty of locating the cutoff point between experimental development and the related activities required to realize an innovation (OECD 2002, paragraph 111). Most definitions of R&D set the cutoff at the point when a particular product or process reaches 'market readiness.' At this point, the defining characteristics of the product or process are substantially set (at least

Figure 5. China's investment in R&D, 1991-2010



Source: China Statistical Yearbook, table 20-40, various years

Figure 6. The supply of R&D personnel in China, 1991-2009



Source: China Statistical Yearbook, table 20-40, various years

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for manufacturers if not also for services), and further work is primarily aimed at developing markets, engaging in preproduction planning, and streamlining the production or control system."

3. Technology Transfer

a) Sino-foreign joint ventures

The decline of China's R&D intensity from 1980 to 1997 corresponded to a national strategy of "Shichang Huan Jishu", or Trading Markets for Technology" (TMFT). China's failed experience of industry upgrading through importing equipment and production lines in the late 1970s prepared the way for a strategy, begun in the mid-1980s, of forming joint-ventures (JVs) with foreign companies (Lu and Feng 2002; Sun 2002; Naughton 2007, 357). In return for investing in a JV and sharing its technology with a Chinese SOE, a foreign company would be granted privileged access to the Chinese domestic market. With the growth of China's economy, control over access to its burgeoning domestic markets gave the Chinese government enormous bargaining power in dealing with foreign companies. Under TMFT only those companies that were willing to share technology would be allowed access to the Chinese market.

The logic behind the TMFT strategy was import substitution. In the decade after China opened up to the West in 1972, the nation had spent more than US$8 billion importing manufacturing equipment (Li and Huang 2001, 648). Besides the strain on scarce foreign reserves, by the early 1980s it had become apparent that Chinese firms lacked the absorptive capacity to improve upon the embedded technology. New methods of technology transfer were urgently required. In the early 1980s, moreover, the import of foreign products increased dramatically. For example, the number of cars imported into China increased from only 1,401 in 1981 to 105,775 in 1985 (China Automotive Industry Year Book 2003, 26).

Indeed, the idea of TMFT originated from the automobile industry. In 1978 the Chineses automobile industry had begun to negotiate with foreign companies about setting up cooperative production projects using imported equipment. To convince the State Council, in 1983 the China National Automobile Joint Company (CNAJC), the government agency that managed the state-owned automobile industry at the time, issued a report about the benefits of engaging in technology trade with foreign companies. In this report, Bin Rao, the head of CNAJC, suggested that, because of the massive importation of foreign cars in the early 1980s, "China's automobile industry should take the path of importing advanced technologies and carrying out cooperative design and production… [The strategy is to] introduce foreign investment and technology/product design, and increasing the manufacturing localization of parts and components" (quoted in Teng 2003).

Also in 1983, while negotiating with foreigners in setting up a telecommunications equipment JV, a State Councilor Jinfu Zhang made it clear to Chinese industry that the goal was to acquire technology. As Zhang out it: "[The] strategy is to trade the market for technologies. We should import, assimilate and absorb high technologies from foreign partners" (quoted in Feng 2010, 74).

The first JV, approved in 1984, was Shanghai Bell to manufacture telecommunications equipment. The Shanghai municipal government owned the Chinese SOE. The foreign partner was Belgium's Bell Telephony Manufacturing Company, which was not a technology leader but was seeking a rapid expansion of its markets. In 1985 the first automobile JV was established between Shanghai Automobile Industry Corporation, owned by the city of Shanghai, and Germany's Volkswagen. Subsequently, JVs were set up in a large number of manufacturing sectors at a rapid pace. It has been estimated that between 1978 and 2000 more than 80 percent of direct foreign investment went to JVs, with an emphasis on automobiles, chemicals, and electronics (Chen and Yue 2002).

To facilitate the growth of JVs, and thereby the rate and range of technology transfer, the Chinese government made huge investments. Large-scale SOEs, particularly those that demonstrated high levels of performance, were encouraged to establish partnerships with multinational companies. As a part of the state-owned industrial system, JV companies enjoyed priority in receiving loans from domestic financial institutions. In addition, JV companies also received tax incentives for foreign investment and favorable tariff schemes for import substitution. Entry barriers in a number of sectors such as automobiles, machinery, and chemicals protected SOEs and JVs from domestic and international competition (Feng 2010, 75-78).

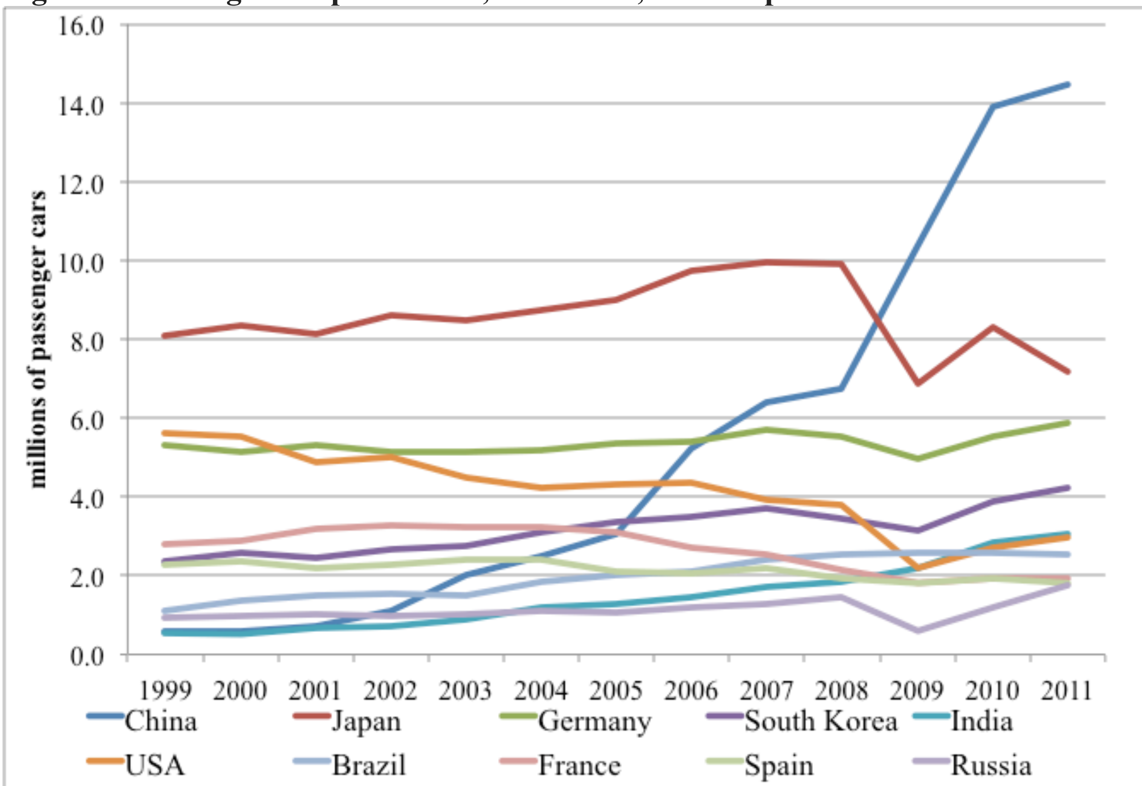
The JV agreement negotiated between China and foreign companies involved complex and broad-range technology transfers, including production, R&D, sub-contracting, marketing, after-sale services, and local human resource training (Mu and Lee 2005). In practice, technology transfers occurred in two major ways, product localization and training engineers.

The JV developed its productive capabilities step by step through targeting local-content goals set by the Chinese side (Segal and Thun 2001). For example, Shanghai-Volkswagen, the automobile JV, set the goal of localizing the production of 50 percent of components for its first imported model, but actually achieved 70 percent within five years. Shanghai-Bell started by assembling imported modules, and later moved to the manufacture of sophisticated components, such as custom integrated circuit (IC) chips.

Meanwhile, the JVs transferred technology through training engineers. The Chinese industrial ministries intentionally organized engineers from other parts of the domestic industry to get training or job rotations at the JV firms. In cases like Shanghai-Bell in telecommunications equipment, this training was the JV returning the favors granted by the Ministry of Posts and Telecommunications (Mu and Lee 2005). In other industries like automobiles and semiconductors, the nation's elite engineers were mobilized to facilitate technology transfer (Feng 2010; Li 2011). In both cases, the JV firms became industry-specific "schools" for the domestic engineers. After gaining experience at the JV, many of these engineers moved on to higher salaries and even more challenging positions at emerging indigenous companies (Mu and Lee 2005).

As shown in Figure 7, in 2009 China became the world's largest manufacturer of passenger cars, by number of units produced, surpassing Japan, and in 2010 and even more so in 2011 China produced more passenger cars than Japan and Germany combined.

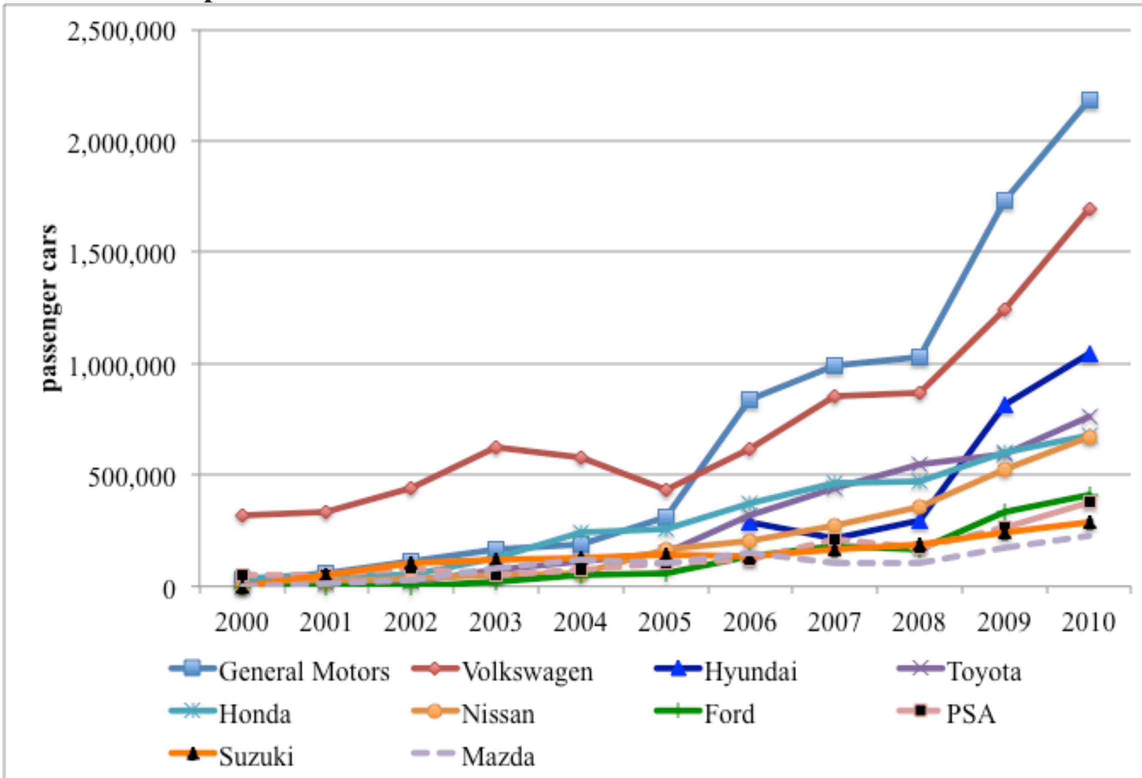
Figure 7. Passenger car production, 1999-2011, in the top 10 nations in 2011



Source: "Production Statistics" at International Organization of Motor Vehicle Manufacturers website, http://oica.net/category/production-statistics/

The leading foreign companies in China's spectacular ascent in the automobile industry can be seen in Figure 8. Until 2005, Volkswagen, through its JVs with FAW and SAIC, was the leading producer of passenger cars in China, but since then has been surpassed by General Motors through its JV with SAIC. In 2001 the ten companies shown in Figure 8 produced 84 percent of China's total production of passenger cars, and in 2010 they still accounted for 60 percent. With the growth of car production in China, however, over this period these top 10 increased their combined production 14-fold, from 588,474 units in 2001 to 8,335,763 units in 2010. While these foreign companies remain central to China's capacity and capabilities in motor vehicle manufacture, as we shall discuss in the next section of this paper, they are being joined by indigenous Chinese competitors, producing and competing in the car market on their own.

Figure 8. Passenger car production in China, 2000-2010, by the top 10 foreign companies in 2010



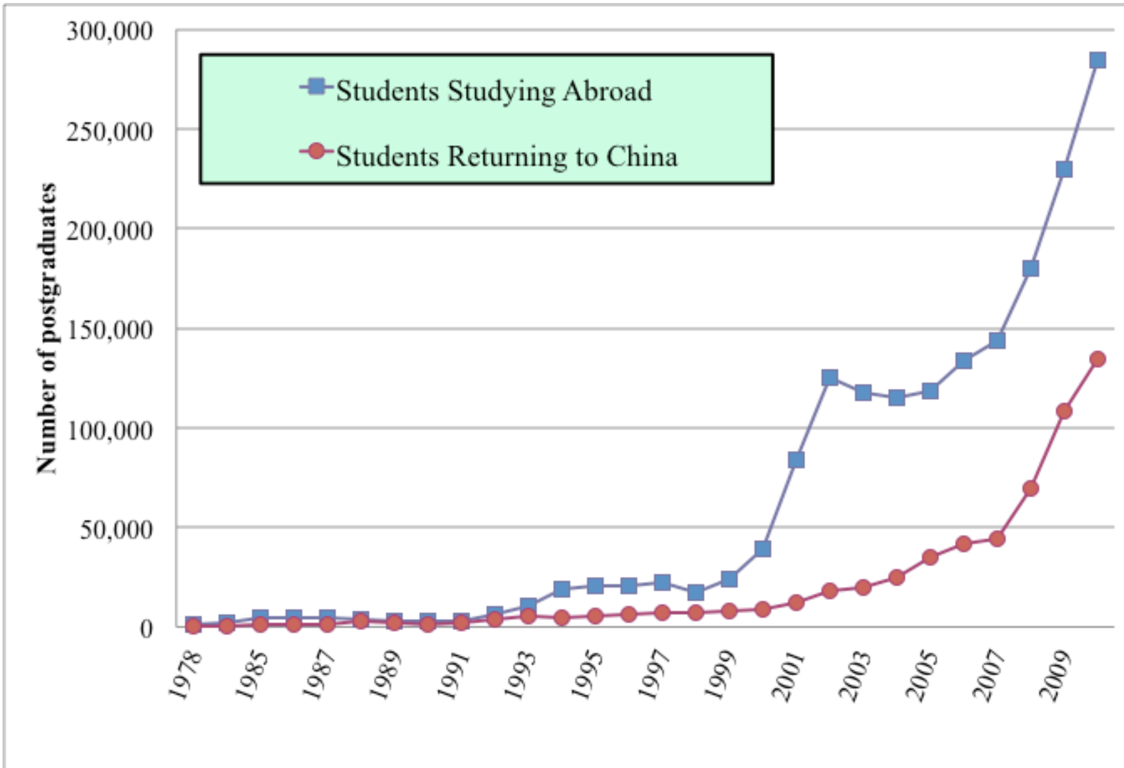
Source: "Production Statistics" at International Organization of Motor Vehicle Manufacturers website, http://oica.net/category/production-statistics/

b) Reverse brain drain

Any nation that seeks to embark upon a path of indigenous innovation requires an educated labor force. In making these investments, however, the problem for a still-poor nation is that some of its best and brightest college graduates might leave the country to seek further education and work opportunities abroad. When this out-migration occurs on a large scale it is known as "brain drain". For example, in the 1960s, 1970s, and 1980s South Korea and Taiwan experienced substantial brain drain, with the United States as the favored destination (Lazonick 2009a, ch. 5) So too, in the 1980s, 1990s, and 2000s, there were large-scale outflows of college-educated labor from China and India, again primarily to the United States.

Figure 9 shows the outflow of students from China since the beginning of economic reforms in 1978. This movement increased substantially in the first half of the 1990s but then took off dramatically in the 2000s.

Figure 9. Chinese postgraduate students studying abroad and returning in China, 1978 to 2010



Source: China Statistical Yearbook 2011, table 20-10

The United States encourages the international migration of college-educated people through the availability of non-immigrant "H-1B" and "L-1" work visas (which are allocated mainly to college graduates) as well as employment-based preferences in the allocation of permanent resident visas (Lazonick 2009a, ch. 5).[6] During the decade of the 2000s, 46.5 percent of all H-1B visas and 36.9 percent of all L-1 visas went Indians, but Chinese were second in H-1B visas with 6.3 percent and also had 2.3 percent of all L-1 visas. A total of almost 96,000 Chinese nationals were able to work in the United States on these two types of non-immigrant visas during the 2000s (US Department of State 2012).

As can be seen in Figure 9 above, in the 2000s there was a sharp increase in the number of Chinese postgraduate students who had been studying abroad who returned to China. More generally, China has been the beneficiary of the phenomenon of "reverse brain drain" or "brain gain" that nations such as South Korea and Taiwan experienced from the late 1980s (Saxenian 2006; Lazonick 2009b, ch. 5). These returnees brought knowledge and experience of advanced technology as well as global contacts back to China. In Beijing and Shanghai,

[6] An H-1B visa enables a company (U.S. or foreign) with operations in the United States to employ a non-immigrant in the United States for up to two consecutive periods of three years each plus an additional year if the employer is sponsoring the employee on the H1-B visa to obtain a permanent resident visa that can ultimately lead to citizenship. An L-1 visa enables a company (U.S. or foreign) to bring personnel who have previously been employed by that company for at least a year abroad to the United States for "training" periods of five to seven years, again with the possibility of ultimately converting the non-immigrant visa to an immigrant visa.

more than 80 percent of the returnees who start a business hold graduate degrees from an overseas institution (Zhang 2008; Kaufman 2003).

The return of entrepreneurial Chinese who had been working in the United States began during the Internet boom of the late 1990s. Many of them used the contacts that they had made there to secure backing from U.S. venture capitalists to start Internet companies in China. Some became highly successful by finding ways to cater to the unique demands of the Chinese market (Zhou 2008; Zhou and Hsu 2011). China's Internet giants of today that were founded by returnees include Baidu (China's Google), Sohu (China's Yahoo), Dangdang (China's Amazon), and Renren (China's Facebook).

In the late 1990s, these expatriate Chinese entrepreneurs were able to choose when and under what conditions they wanted to return. Earlier, for example, if a Chinese student went abroad, his or her family had to pay a penalty if he or she did not return. By the 1990s, however, the government dropped such attempts to control the international migration of students. Instead, as it funded research projects such as the 973 Program, Knowledge Innovation Program of the Chinese Academy of Science and others, the Chinese government aggressively recruited overseas Chinese scientists and engineers to bring their knowledge and experience back home (Zweig 2006).

By 2000 the Chinese government had become aware of the importance of these types of expatriate Chinese for building China's high-tech industry. While increasing the number of students funded to study abroad (although most such Chinese students were *not* funded by the Chinese government), the central government adopted a strategy of competing for talent on the international labor market. In 2000 China's President Jiang Zemin made public statements about China's need to compete on the global market for talent – especially to lure back its own people (Zweig 2006).

It has not just been the central government that has become involved in this global recruitment process. Local governments that seek to support startups in high-technology parks compete even more fiercely to attract returnees to their localities. Incentives often include tax breaks for new firms, cheap or free land use, subsidized housing, tax-free imports of equipment and components, and schooling for children. Returning entrepreneurs with foreign technology and financing to build substantial ventures can shop around various locations for the best deal (Li 2011).

During the 2000s returnee-founded companies were highly concentrated in the ICT sector, since new ventures can be easily inserted into the well-defined global production networks in ICT, while the very existence of these global networks means that returnees' global contacts and knowledge are highly valued (Zhou 2008; Zhou and Hsu 2011). The emergence of China's highly successful solar panel industry indicates that the impact of returnees on China's industrial development is extended well beyond the ICT industry. Returnee scientists and engineers founded indigenous Chinese solar companies such as Suntech Power and Trina Solar.

4. Indigenous Innovation

Computer electronics during the early reform period

China started its economic reform in the late 1970s. The initial reform took place in the rural sector by allowing the experiments of household farming in a few poor provinces. The "Household Responsibility System" was soon implemented nationwide. By the beginning of the 1980s, there was a rapid growth of agricultural productivity as well a significant increase in household income (Lin 1988, 1992). Fueled by the large pool of labor released from the farmlands, the rural industry had a boom, particularly in the coastal provinces. Much of the seemingly infinite supply of labor migrating out of the countryside was subsequently absorbed by foreign direct investment in an "offshoring" process that over the 1990s shifted a significant share of the world's labor-intensive industries to China.

The success in reforming the rural sector encouraged the Chinese government to create similar incentives for the urban and industrial sectors. Inside the government, the reform involved fiscal decentralization. In the early 1980s a system of fiscal contracts that divided tax revenues among levels of government (*caizheng baogan*) replaced the former planning system in which the center controlled the flow of all revenues (*tongshou tongchou*) (Oi 1992). In the mid-1990s this fiscal arrangement evolved into a tax system that divided sources of tax revenues between the central government and local governments. With both incentives and funds, local governments in China became actively engaged in promoting economic growth (Walder 1995, Morawetz et al. 1996).

The reform of the industrial sector loosened the central government's grip over business enterprises. As an imitation of the "Household Responsibility System", a "Factory Director Responsibility System" was first set up to introduce economic incentives to managers and workers in state firms for higher sales and productivity in the early 1980s. State firms were allowed to sell part of their output outside the planned system. By 1993 "State-Operated Enterprises" were officially retagged as "State-Owned Enterprises" as a result of managers' growing authority in running their firms. A new category of firms, non-governmental (*minying*) companies, was allowed to operate in the cities. Encompassing SOE-spinoffs, "collectively-owned" companies, and private ownership, the non-governmental firms operated with autonomy from state direction or intervention.

As early as the mid-1980s, initiatives from the early reform already gave birth to a group of non-governmental S&T companies. Some of these companies became the pioneers in engaging in indigenous innovation. Against a background of perceived technological backwardness in China, the innovative successes that they achieved were remarkable. As documented in the pioneering research of Qiwen Lu (2000) in his book *China's Leap into the Information Age*, the prime examples of the early indigenous innovators were computer companies. Drawing on Lu, we consider the cases of Stone, Legend (renamed Lenovo in 2004), and Founder.

As a pioneer of China's computer industry, Stone was founded by a group of alumni of Tsinghua University in 1984. In joining Stone, these elite engineers gave up their "iron rice bowls" – secure state jobs in government research institutes as well as state-owned enterprises. In the same year, Legend was launched by the Institute of Computing Technologies of the Chinese Academy of Science (CAS) as a commercialization vehicle for the institute's technology.[7] Similarly to Legend, Founder sprung out of Beijing University's Institute of Computer Science and Technology to commercialize its electronic publishing system (EPS) technology in 1986.

As they were non-governmental companies, all the three ventures were established outside central or local budgetary control. Government agencies or state-owned enterprises that invested in these companies would neither interfere with their operation, nor bail them out if the companies were to fail (Lu 2000, 125). Ownership structures of the three companies were "collectively owned", although individuals could not claim equity shares. Managers had decision-making autonomy in running the non-governmental companies. As described in the agreement between CAS and Legend, the spin-off's executives had "full autonomy in managerial decision-making, financial budgeting, and employee recruitment" (Lu 2000, 65).

Since they were financially independent entities, the survival of the non-governmental companies depended on selling products on the market. Yet, initially at least, it was technological capabilities transferred from the nation's S&T infrastructure that formed the foundation for these computer companies to generate marketable products through indigenous innovation. Stone started by selling electronic printers with Chinese-character output capability, a feature in which very expensive imported models had previously dominated. By re-engineering a conventional printer so that it would be capable of outputting Chinese characters as well, Stone incurred much lower costs than its international competitors.

With full access to CAS's science and technology resources, Legend launched its growth by the successful commercialization of a Chinese word-processing add-on card. The technology was invented by a state scientist at CAS, and could be used with existing IBM PCs and clones (performing a similar function as Stone's stand-alone Chinese word processor). Legend transformed this invention into a popular product through investing in distribution channels and manufacturing facilities.

EPS, Founder's first successful product, emerged from a state-supported project to develop high-resolution Chinese electronic publishing technologies. In the late 1970s, electronic printing of the Chinese language was a huge challenge for the computer industry. A computer scientist at Beijing University, Xuan Wang, came up with a solution of compressing Chinese fonts to solve the technology constraints of insufficient memory for Chinese ideographic characters in computers at that time. With funding from the state, Wang invented the raster image processor (RIP), the core technology of the Chinese-enabled laser typesetter. By controlling the design and manufacture of RIP, Founder quickly became the leader in the Chinese electronic publishing industry.

[7] The original name of Legend was "New Technology Development Company of the Research Institute of Computing Technology of CAS" (ICT Co.).

In addition to taking advantage of science and technology transferred from government research institutes, the non-governmental computer companies also raised seed capital from the state sector, especially from local governments and state-owned enterprises. But, as a distinctive feature of China in the 1980s, the state largely restrained itself from extracting rents from these successful non-governmental companies, allowing them to reinvest profits for further growth. For example, when the group of engineers founded Stone, they secured a "venture loan" of RMB20,000 from Evergreen Township of Beijing's Haidian District, where the company was located. Initially, government officials of the township were involved in the affairs of the company, and the township claimed 60 percent of Stone's profits. In 1985, however, most of the officials resigned from Stone as a result of the Communist Party's restriction on the direct involvement of party officials in commercial ventures. By 1988, Stone only paid the township a fixed annual amount of RMB526,000, a small fraction of its total revenues. Similarly, Legend received an initial loan of RMB200,000 from CAS, which was later repaid as a fixed annual payment of RMB1.2 million. This amount initially accounted for 40 percent of Legend's revenues, but by 1988 it was less than one percent and by 1991 less than .02 percent. Even Founder, which had the closest relations with Beijing University, retained the majority of its earnings.

The control over revenues and earnings gave managers of the non-governmental enterprises a critical foundation for investing in innovative strategies. As early as the 1990s, Founder was able to spend more than RMB15 million per year on R&D, all derived from retained earnings. In contrast, the state allocated a total of RMB10 million to government funding of research and development in the electronic publishing system (Lu and Lazonick 2001, 70). With such financial capabilities, the non-governmental computer companies were able to invest heavily in integrating R&D, manufacturing, marketing, and services at a time when traditional state-owned enterprises simply carried out instructions and fulfilled production quotas. Stone, Legend and Founder all established nation-wide distribution networks. Legend, in particular, integrated before- and after-sales services in its distribution channels, and made these services available in all the major cities of China. This distribution network in turn allowed the company to access a larger market and to learn from the customers, both of which are critical to the process of innovation.

To sustain their rapid growth, the non-governmental companies had to build their technological capabilities continuously. Enterprise management had the authority to decide which employees to hire and how to structure their remuneration. Such control over decision-making and resource allocation was essential for non-governmental companies to lure key technologists from the state sector. At Stone, for example, this managerial autonomy in attracting and retaining personnel was necessary to convince key members of the development team for the Chinese word processor to abandon the "iron rice bowls" that they enjoyed as government employees.

By the mid-1990s Legend, Founder, and Stone, had become market leaders in China. Legend grew to be the nation's largest personal computer maker, a position that it has maintained as Lenovo. Founder was the world leader in pictographic language electronic publishing system until 2000, and remains one of China's major high-tech conglomerates. Stone was adversely affected by the flight of its founder and CEO from China after the

Tiananmen incident, and in the 1990s evolved into a diversified conglomerate with little high-tech capability.

The early growth and success of these companies was based on indigenous innovation. Absorbing technology transferred from the state S&T infrastructure and abroad, these computer companies grew by learning how to transform technologies and access markets in ways that generated higher quality, lower cost products. In becoming self-sustaining enterprises, these companies tapped into technological resources of China's S&T infrastructure. Scientist-turned-managers with intimate knowledge of technology gained decision-making autonomy, or strategic control, so that they were able to set the indigenous innovation strategy. With the State imposing self-restraint in appropriating the gains from innovative enterprise, these companies not only received seed capital from the state sector, but also were able to retain revenues for investment in building organizational capabilities. The ability to allocate resource in the organization allowed the non-government S&T companies to reward, motivate, and integrate employees in ways that state-owned companies could not. These changes in state-firm relations, combined with these S&T resources provided by the legacy of state investment, put in place the social foundations for the computer companies to engage in the process of indigenous innovation.

Automobiles and telecommunications equipment in the 1990s

While permitting the emergence of business enterprises in the non-state sector, the Chinese government continued to rely heavily on SOEs, which received infusions of capital, underwent management restructuring, and invested in new technologies. In the mid-1980s SOEs (then still called state-operated enterprises) formally embraced the policy of "Trading Markets for Technology" (市场换技术, shichang huan jishu). Up until 2004, the formation of JVs between SOEs and foreign multinational companies was the primary national strategy for industrial upgrading in the state-owned economy (Lu and Feng 2005).[8]

Automobile manufacture was the first industry to introduce the TMFT strategy though JVs. In 1978, for the first time, the Chinese government initiated a talk with Germany's Volkswagen with the goal of establishing a JV automobile enterprise. This talk led to the 1983 JV agreement between Shanghai Automobile Industry Corporation (SAIC) and Volkswagen. From 1983 to 2000 71 JV agreements between China and multinational carmakers were signed, giving birth to over five hundred JV companies from car assembly to parts and components manufacture. By 1994 the largest eight state-owned automobile enterprises, First Auto Works (FAW), SAIC, Dong Feng, Beijing, Guangzhou, Tianjin, Chang An, and Chang He, had all established JVs with foreign companies (Feng 2010, 73). It was only after the Chinese government removed the strict barriers to entry in automobile manufacture in 2001 that indigenous companies began to challenge the dominance of the JV carmakers.

Over this period, the Chinese automobile industry experienced rapid growth, as can be seen in Table 7 above. In 1982, before the establishment of the first joint venture, the entire

[8] The histories of the automobile and the telecommunications industries are based on Feng (2010).

China industry produced merely 4,000 vehicles. By 2000 the nation had a capacity to produce 600,000 vehicles annually (Feng 2010, 86).

This massive expansion of productive capacity was driven by a strategy that emphasized production localization and economies of scale (Lu and Feng 2005; Segal and Thun 2001). Shanghai-Volkswagen, one of the most successful JVs, set the example in production localization. When Shanghai-Volkswagen imported its first sedan model "Santana" in 1985, the Shanghai municipal government explicitly set the local content target at 25 percent by 1988 and 50 percent by 1989. Yet Shanghai-Volkswagen, driven by the incentive of replacing expensive imported components with lower-cost local ones, attained 60 percent of production localization of the "Santana" in 1989, 70 percent in 1990, and 92 percent in 2000 (Feng 2010, 98). By 1998, when SAIC established its JV with General Motors, it took only two years to achieve 40 percent of localization of the newly imported Buick model.[9] The success of automobile JVs in capacity building was reflected in their sheer size after two decades of growth. In 2005 SAIC became the first Chinese auto company listed among the Global Fortune 500. FAW got onto the list one year later.

Yet the pursuit of the localization strategy and manufacturing efficiency came with a cost. While the automobile JVs grew bigger than ever, they generally lacked the ability to develop new products. None of the JV automobile companies systematically developed new models over the TMFT period.[10] The largest three JV carmakers, Shanghai-Volkswagen, FAW-Volkswagen and Dong Feng-Citroen, continued to manufacture three imported models, Santana, Jetta, and Fu Kang respectively, for almost two decades. By the end of the 1990s, R&D departments at the big automobile JVs had all been shrunken and marginalized.

Joint-product development was supposed to be a part of the joint-venture agreement. Yet the multinational carmakers had little interest in transferring technologies to China that would create future rivals. The co-development of a new car model – Santana-2000 – as part of the Shanghai-Volkswagen JV project illustrated the difficulties of the Chinese JVs in product development. Initially, Volkswagen insisted on building the JV as primarily a manufacturing base for the Santana sedan model. SAIC bargained hard for a co-development project in the early 1990s. Aided by political pressure from the Chinese government, SAIC finally made Volkswagen launch the Santana-2000 project in 1995, ten years after establishing the JV firm. Even so, Volkswagen carried out the entire project at its Brazil subsidiary, with only 10 Chinese engineers being sent to participate (Feng 2010, 105). Similar cases were prevalent among the auto JVs – their R&D departments were either staffed with multinational employees or simply not functioning.

As a result of neglecting product development activities, automobile JVs remained dependent on technology transfer from foreign partners to improve their productive capabilities. In 2005 the Chinese government's introduction of "Indigenous Innovation" policy began to place political pressure on the automobile JVs to deliver "innovation" by generating new car models. Several JV companies responded by outsourcing the design

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9 Although the marque was Buick, the actual car was an Opel from GM's German subsidiary; see Dunne (2011, ch. 8).

10 Only Dong Feng developed one new model 1996, but the model was manufactured on a very small scale.

work of new models to their multinational partners. FAW, SAIC, Dong Feng and other major automobile firms that participate in JVs have continued to sign new JV contracts with multinationals, some of which will last beyond 2030 (Feng 2010, 143). By depending on the JV business model, these Chinese automobile companies have ceded to the foreign partners strategic control over the allocation of company resources to innovation.[11]

Although TMFT was the dominant industrial policy for two decades, the JV business model did not dominate all industrial sectors. Each time the Chinese government lowered the legal barriers to entry of non-governmental businesses, indigenous companies emerged outside of the JV industrial system. National policy actually tried to stifle some of the companies engaged in indigenous innovation. And in some industries, indigenous innovators even outcompeted the JV firms. Huawei and ZTE in the communications equipment industry are prime examples of growth through indigenous innovation in the 1990s.

Similar to the automobile industry, the telecommunications equipment sector was one of the early adopters of the TMFT strategy. As early as 1984, Shanghai-Bell was created as the first Sino-foreign JV in the manufacture of telecom switches. Between 1984 and 1993, major state-owned telecom companies established JVs with multinationals. Through pursuing an aggressive strategy of product localization, leading telecom joint-ventures grew fast over the 1990s. By 2000 Shanghai-Bell became the largest provider of telecom switches in the world.

In contrast to the protection that the Chinese government gave to SOEs in the automobile industry in the 1980s and 1990s, it allowed domestic and international competition in the telecom equipment sector by removing most of the entry barriers in the early 1980s. During the 1980s there were more than 200 domestic entries in telecom equipment manufacture. Most of the entrants were SOE-spinoffs, "collectively-owned" enterprises, and private companies – the sort of non-governmental companies permitted by the early reform. As outsiders to the state-controlled enterprise system, the telecom entrants did not have the possibilities to grow through forming JVs with multinationals. By the end of the 1990s, cut-throat competition in the low-end market eliminated the majority of these young companies. Yet, the winners of the domestic market, Huawei and ZTE, grew to become substantial global enterprises.

ZTE was founded in 1985 by a group of engineers as a spinoff from a state-owned factory. With a small grant from the factory, the ZTE founders were to find new sources of revenue in Shenzhen. In 1993 ZTE signed an agreement with the state factory in which ZTE paid a fixed rate of return to the factory in exchange for autonomy. Huawei was founded in 1987 as a collectively-owned enterprise. Its initial investment of RMB20,000 came from the founders' personal savings. From the beginning, the two companies were autonomous business enterprises.

[11] As a result of GM's desperate need for cash in 2009, when it went bankrupt and had to be bailed out by the US government, SAIC was able to increase its ownership stake in Shanghai General Motors Corp. from 50 percent to a controlling interest of 51 percent (Dunne 2011, ch. 21).

Huawei and ZTE entered the telecom equipment market by selling inexpensive analogue telecom switches, an outdated technology utilized by most telecom entrants in the 1980s. Meanwhile, the technology of advanced digital telecom switch models had been imported through Sino-foreign JV projects. But the manufacture of the imported model relied on the import of a high-performance integrated circuit (IC) chip. Despite having formed the JVs, telecom multinationals would not share the core technologies embedded in the chips nor would they permit their Chinese partners to fabricate the high-performance IC chips. Chinese JV telecom companies were pressing their foreign partners for the supply of the chip technology.[12]

Huawei and ZTE, however, decided to develop the digital telecom switch technology indigenously. In their early years, both companies committed almost all of their revenues to product development (Fan 2006; Lu 2006). Huawei even borrowed high-interest loans (20-30 percent) to fund its research and development. Still the difficulties for indigenously developing digital telecom switch technology were immense. Besides huge technological uncertainty, these companies faced a major organizational challenge. The allocation of most company resources to technological development placed constraints on their ability to reward their employees. Between 1988 and 1993, employee turnover at Huawei was as high as 30-50 percent (Feng 2010, 210). In order to motivate the workforce, both Huawei and ZTE came up with the idea of sharing ownership with its employees. At ZTE, managers and engineers were offered equity shares. At Huawei, founding members distributed company shares among employees.

A technological breakthrough came in 1991. A state lab named Center of Information Technology came up with an ingenious idea that significantly lowered the performance requirements of IC chips in building large-scale digital telecom switches. The lab's design – a PDSS model named HJD-04 – adopted a distributed computation technology to spread the workload from one high-performance chip in conventional designs to several lower-performance chips. Therefore the HJD-04 model could achieve a similar level of high performance as the imported ones while still using inexpensive, mass market IC chips.

Huawei and ZTE quickly seized the opportunities in the diffusion of this new technology. Both companies discontinued their own projects of digital switch development, and started new ones based on the distributed architecture. Developers of the HJD-04 model were hired as consultants, and some of them were even engaged jointly by the two companies. In 1993 both Huawei and ZTE launched their first digital telecom switch models, C&C08 and ZXJ10, respectively. These products were remarkable indigenous innovations, achieving similar levels of quality as imported models. Not only was it possible to produce them indigenously but these switches were far less expensive than the imported technologies.

Throughout the 1990s Huawei and ZTE continued to commit to technological learning. Huawei invested more than ten percent of its revenues in R&D activities, while ZTE kept an average R&D intensity at around ten percent (Fan 2006). As startup companies, Huawei and ZTE had to expand their technological capabilities rapidly. Over the decade, Huawei and ZTE made numerous organizational arrangements for joint product development with state

[12] The transfer of custom IC technology for telecommunication occurred in 1993.

labs, universities, and even JV companies. In many cases, after the joint projects ended, participants from the state sector came to work with Huawei and ZTE where they were better rewarded than at their former employers for their contributions to innovation. In the late 1990s, Qingdao-Lucent, a Sino-US telecom JV, lost half of its testing engineers to Huawei, while a large number of engineers trained at Shanghai-Bell moved to Huawei and ZTE.

The two companies, particularly Huawei, made huge investments in integrating after-sales service into their operations as part of their innovation strategy. Thousands of engineers were sent to the customers' operational locations to solve their technical issues, and then sent feedback to their employer's product development department. At that time, the multinationals and JV firms ignored the problems experienced by local telecom operators with small budgets. By offering low-cost products bundled with high-quality services, Huawei and ZTE outcompeted the multinationals and JV firms in rural or remote markets, where they constructed their first revenue bases. By the early 2000s Huawei and ZTE had grown through indigenous innovation to become substantial telecom equipment enterprises.

During the TMFT era, indigenous innovation also occurred in the automobile industry when after at the end of the 1990s the state permitted domestic entry. Out of fierce competition, a number of indigenous innovators had some success in the domestic market. Geely, Chery, BYD and other non-governmental carmakers engaged in an innovation strategy similar to what Huawei and ZTE did – growth through the indigenous development of lower-cost, higher-quality automobiles to become viable competitors to multinational and JV firms. These companies still have to make considerably more progress in improving quality and reducing costs. But what is important at this point is their emergence as increasingly well-known and respected brand names.

In 2010 no indigenous Chinese companies were represented among the top 15 car producers in the world, although combined the top 15 companies (six Japanese, three German, two each American and French, and one each South Korean and Italian) produced 8.6 million cars in China. Of the next 25 largest car producers in the world, however, 19 were Chinese, with a total output of 5.9 million cars, or 42% of China's car production. (Note: There is some double-counting between foreign and indigenous producers because of JVs.)

Whereas JV firms lack of research and development, indigenous carmakers stress developing new car models. From the late 1990s to the mid-2000s, Geely developed nine and Chery seven new car platforms. The intense development activities in these companies accelerated learning and innovation, but also required heavy inputs of organizational resources. As young companies with limited technological resources, the carmakers learned by devolving decision-making power to frontline engineers, who thus are able to mobilize organization-wide resources in problem solving (Feng 2010, 166-184). As a result these companies have been able to integrate the skills and efforts of personnel across layers of hierarchy and functional divisions of the production process into the organizational learning processes that are essential for innovation.

China's experience in the 1990s, therefore, consisted of two growth strategies. Forming JVs with technologically advanced foreign companies proved to be an effective policy to implement import substitution and deploy advanced production capabilities. Indeed, foreign investments have significantly contributed to China's rapid growth. Yet, by ceding the power to foreign companies to make decisions about innovation strategies, or what we call strategic control, the JV companies were incapable of improving and innovating on the basis of imported foreign technologies.

In contrast, indigenous companies like Huawei and ZTE committed to an innovation strategy from the beginning. Strategic control enabled these indigenous companies to combine technological resources derived from state investments as well as those transferred from foreign investment to achieve innovative success. Financial commitment through the reinvestment of earnings, often aided by funds from regional governments, enabled indigenous startups to sustain the innovation process to the point at which they became sufficiently large to access the banking system. In the process of indigenous development, as we have mentioned, they pursued organizational integration of employees through sharing ownership (Huawei and ZTE) and empowering frontline engineers (in automobile companies), in addition to their ability to lure key employees from the state and joint-venture firms.

Semiconductors in the 2000s

With China's accession into the World Trade Organization in 2001, the government allowed competition in an increasing number of industries. Meanwhile, the capabilities accumulated over two decades of growth prepared Chinese companies to enter and compete in more technology-intensive and capital-intensive industries. By the beginning of the 2000s the inflow of Chinese returnees, or "sea turtles", on an increasingly larger scale provided another mode of technology transfer (Saxenian 2005; Zhou 2008).

These educated Chinese who had gone abroad for graduate degrees and/or work experience brought back skills, ideas, and global contacts to domestic industry. To transform thee capabilities into \successful entrepreneurship, the expertise of the returnee is often combined with seed capital from China's local governments, which sought continuous growth though active investments in high-tech industries. The recent history of the semiconductor industry illustrates a business model driven by returnees and local governments during the 2000s.[13]

China established a small semiconductor industry in the era of planned economy (Simon 1987). In the late 1980s, the state-owned semiconductor industry embraced the JV strategy as was the case in automobiles and telecommunications. Throughout the 1990s, the Chinese government initiated two national projects (i.e. Project 908 and Project 909) to build large Chinese semiconductor firms. By the end of the period, however, as a result of lacking strategic control, organizational capabilities, and committed finance, the Chinese state-owned and JV semiconductor sector failed to develop technology and achieve economies of scale required to compete globally.

[13] The history of the semiconductor industry is based on Li (2011).

Initiated in 1990 by the State Council, project 908 is the first billion-RMB Sino-foreign cooperative project in semiconductors. The Chinese invested two billion RMB to import a 200mm wafer fabrication line from Lucent Technologies, and had it installed as part of the facilities of a major SOE, Huajing Microelectronics. But neither the SOE nor the government anticipated the huge and constant investment needs for advanced chip manufacturing, resulting in a long delay in bringing the factory online. The line finally started fabricating chips in late 1996, but the SOE lacked the absorptive capacity to profit from the investment.

In 1997 the Ministry of Microelectronics launched Project 909, in which the central government teamed with the city of Shanghai to finance a Sino-foreign JV project in semiconductors. With US$500 million from the Chinese and US$200 million from Japan's NEC, this project led to the establishment of a giant semiconductor JV firm Huahong-NEC. The firm not only imported state-of-the-art fabrication lines from Japan, but also installed management from NEC. The strategy was to learn both technical and management skills from the foreign partners. In the first three years, the plan worked well. Huahong-NEC was able to ramp up its fabrication lines in only two years. Supported by large orders from NEC, the JV was very profitable in its first year of operation.

Yet Huahong-NEC was no exception to the problems of the Sino-foreign JVs. At the end of the management agreement with NEC, the JV found that it continued to rely on its foreign partner for markets, technology, and management. As a demonstration of its lack of strategic control, Huahong-NEC suffered huge losses in the early 2000s as the combined result of the downturn in world markets and the decline of NEC's own semiconductor division. The losses also discouraged further investment from the Chinese state.

The turning point was the year of 2000 when the government removed entry barriers to semiconductors. The "Policies on encouraging the development of software and integrated circuit industry" (鼓励软件产业和集成电路产业发展的若干政策), also known as Circular 18, issued by the State Council in June 2004, provided incentives to domestic semiconductor firms regardless of its ownership. The policy led to the establishment of Semiconductor Manufacturing International Corporation (SMIC) and Grace Semiconductor in 2001, two giant semiconductor foundries. Both firms involved founding members returning from the US, Taiwan, Singapore and other major locations of the global semiconductor industry. Learnt from the success of the Taiwanese semiconductor industry, the founders of SMIC and Grace followed a "pure-play foundry" operation model invented by TSMC – that is specializing in the manufacture of chips and providing production capabilities to semiconductor firms designing chips. The growth of dedicated manufacturing capabilities for hire underpinned the explosive expansion of a Chinese semiconductor ecosystem – the number of fabless semiconductor design houses increased from less than 100 in 2000 to over 500 in the mid-2000s (PWC 2010).

Accounting for more than half of China's production capacity, SMIC is the leader and model of the Chinese semiconductor industry in the 2000s. A returnee team headed by Dr. Richard Chang, an ex-senior-manager of Texas Instruments, founded SMIC. Its early investors included Silicon Valley venture capital firms, the city of Shanghai and Chinese banks. The adoption of a foundry business model in SMIC was a result of Chang's experience of operating foundries in Taiwan as well as the foundry backgrounds of key members iof his team. Chang's competition strategy based on economies of scale drove the rapid expansion of SMIC. By 2004, SMIC had already become the world's third largest pure-play semiconductor foundry by revenue, leading China to become a second largest foundry capacity provider after Taiwan.

The extraordinary growth of SMIC was underpinned by active investment from the local governments. The semiconductor business is extremely capital intensive. The latest manufacturing plants (fabrication plants, or "fabs") employing up-to-date technologies cost US$3 billion or more. Over the 2000s, SMIC experienced two rounds of capacity building. In the first round of expansion during 2001-2004, it raised capital from venture capital, public offerings in NYSE and loans from the Chinese banks, in addition to heavy subsidies and investment from city governments to construct fabs in Shanghai and Beijing, and acquire Motorola's fab in Tianjin. By the second round of expansion during 2005-2008, however, SMIC faced tighter constraints in capital after continuous operational losses, and it relies more heavily on working with Chinese municipalities to finance its investments. In its collaboration with Chengdu and Wuhan, the city governments invested in new plants as legally independent firms, but had SMIC to operate under contract arrangements. The city of Shenzhen even planned to finance the construction of a whole new subsidiary of SMIC with 12-inch fabs, and transfer it to SMIC after the project was completed.[14] The financial commitment from the Chinese cities was key for SMIC to remain competitive in the late 2000s.

Innovation in semiconductor fabrication requires substantial skills and experience accumulated in the particular business organization (Kim 1997; Matthews & Cho 2000). SMIC's organizational strategy was to tap into the pool of skills of expatriate scientists and engineers. In its early years, SMIC recruited hundreds of ethnic Chinese engineers and managers from multinational semiconductor companies. From Taiwan's rival foundry TSMC alone, SMIC lured more than 140 production experts. The SMIC offering was the classical bargain from a high-tech start-up, "a chance to be on the ground floor of a pioneering venture, with stock options" (Iritani 2002). Some key experts received as many as 80,000 shares of stock and options in joining SMIC. But as employees they were paid only at prevailing Chinese rates at that time (about 25 to 30 percent of US salaries for senior managers).

As the spokesperson for rival foundry TSMC described it, the capabilities assembled through global hiring allowed SMIC to achieve "an implausibly quick ramp-up of its production facilities and fabrication processes" (Clendenin 2004). It took SMIC's state-of-the-art fabrication line one and a half years from the start of construction to enter mass production. Grace spent two and a half years to go through a similar process, itself an impressive feat.[15] Driven by SMIC and Grace, the semiconductor technology gap between

[14] SMIC's Shenzhen operation was announced in 2008, but the facility was still under construction as of November 2012.
[15] Grace also recruited engineers from Taiwan, but the scale was much smaller than SMIC (Li 2011, 48-51).

China and leading multinationals was closed from 8 to 10 years in the 1990s to 10 to 12 month in the mid-2000s (GAO 2008).

The case of the semiconductor industry illustrates how domestic industries can leapfrog with the aid of returnees. This leap is enabled by allowing the returnee technologists to take strategic control of the domestic firms, and more importantly, making organizational arrangements to integrate the skills and experience of an experienced global labor supply of expatriates into the learning process. Ultimately, the rapid absorption of foreign technology can result in indigenous innovation.

During the 2000s, the local governments renewed their role in economic growth as early investors in high-tech industry. While the local bureaucrats might lack the ability to identify sound investment projects in high-tech industries, the returnee entrepreneurs gained credibility for their overseas training and working experiences in raising capital form the Chinese cities. Although such approach bears controversies of biasing towards returnees vs. domestic peers, it compensated the role needed to be played by a weak venture capital sector, and was critical as sustained finance for path breakers in newly formulated industries. In addition to SMIC, another major success of the city-funded high-tech venture during the 2000s was Suntech, currently the largest solar photovoltaic firm in the world. The sustained venture investment from the city of Wuxi allowed Suntech to be established in the first place, to accumulate capabilities while bearing losses in the first three years of operations, and finally to succeed at the launch of the global market in 2004. Without the financial commitment from the city governments, a Chinese solar photovoltaic industry would barely exist.[16]

5. China's Path as an Unfolding Phenomenon: Catching Up with History

In this paper we have provided a framework for analyzing the role of industrial innovation in the development of the Chinese economy. We have illustrated how investments in physical and human infrastructure along with technology transfer have created the foundations for the emergence of indigenous innovation in a number of key industries over the past three decades. From a theoretical perspective, our analysis of China's path to indigenous innovation demonstrates the importance of the combination of the developmental state and the innovative enterprise in the economic growth of a major national economy.

The case of China demonstrates that the success of the developmental state in fostering a dynamic of growth depends on the emergence of innovative enterprises. In the theory of innovative enterprise, the importance of *indigenous* innovation derives in the concept of "strategic control". Companies that seek to become global competitors in technology industries have to go beyond technology transfer from abroad to develop superior technologies at home. Strategic control over corporate resource allocation gives top

[16] See Hopkins and Li (2012) for a detailed discussionsof the finance from Chinese municipalities in the development of the solar photovoltaic industry. See also Hopkins and Lazonick (2012) for an analysis of innovation and competition in the global solar energy industry with an emphasis on the roles of financial commitment and strategic control in the performance of the US industry.

executives the power to invest in the productive capabilities of the workforce and, through a system of incentives, transform those productive capabilities into organizational capabilities that can engage in organizational learning. The theory of innovative enterprise calls this process “organizational integration”. Building these organizational capabilities inevitably entails high fixed costs that, for innovation to be successful, must be transformed into low unit costs through accessing a large extent of the market. The theory of innovative enterprise calls this process of sustaining the innovation process from the time investments in organizational capabilities are made until the time financial returns are generated “financial commitment”. Taken together, strategic control, organizational integration, and financial commitment constitute “social conditions of innovative enterprise” (Lazonick 2010b and 2012b).

In our view, further research into China’s path to indigenous innovation can be considerably enhanced through the application of the social conditions of innovative enterprise (SCIE) framework.[17] Empirically, in this short paper, we have been selective in treating the relevant literature on investments in physical and human infrastructure, technology transfer, and indigenous innovation. We view this contribution as a “framework” paper that can be useful for integrating large and growing bodies of diverse research into an integrated and coherent perspective on the Chinese development process.

Utilizing the SCIE framework, the case of China can then be integrated into cross-national comparative-historical analysis of the process of economic development and changes in international economic leadership (see Lazonick 2007 and 2010a). For example, in a paper, “Innovative Business Models and Varieties of Capitalism,” Lazonick (2010a) employs the framework to show how and why in the 1970s and 1980s, Japan outcompeted the United States in industries such as automobiles, consumer electronics, machine tools, and memory chips, in which US companies had been dominant, and how Japanese competition was a key catalyst in the transition of the US corporate economy from an “Old Economy” to a “New Economy” business model (see also Lazonick 2009b).[18]

The objective of this type of comparative-historical analysis is to place ourselves, as academic researchers, in the position of both monitoring and comprehending the development of Chinese industry as it unfolds in real time. We call this methodology “catching up with history”: industry researchers are able to analyze major industrial transformations, be they breakthrough innovations or financial crises, as they are happening while placing the unfolding events in the context of a comparative-historical understanding of the dynamics of industrial change. To aid this process of catching up with history, we are in the process of constructing a website called (appropriately enough) “China’s path to indigenous innovation”.[19]

[17] For an overview of the applications of this framework, see Lazonick 2012c. For the case of Japan, see Lazonick 2005.

[18] The integration of China into this comparative analysis is a focus of a project, “Financial Institutions for Innovation and Development,” directed by William Lazonick with funding from the Ford Foundation.

[19] Dongxu Li, Qiaoling Ma, and Xiahui Xia, all graduates students at UMass Lowell, have been working with the authors on the development of this website.

Finally, in carrying out this analysis our interest is not innovation per se. Innovation creates the possibility, although by no means the necessity, that the population can have higher standards of living. Through the generation of higher quality products at lower unit costs, given prevailing factor prices (again, the economic definition of innovation), it is possible simultaneously for workers to have better pay and work conditions, for creditors to have more security in their principal and interest, for shareholder to have higher dividends and share prices, for the government to have higher tax revenues, for the innovating firm to have a stronger balance sheet, and for consumers to have more and better goods and services at lower prices. It all depends on how the gains from innovative enterprise are shared among these stakeholders.

It is the structure of power within business enterprises and through government policy in conjunction with "market forces" that determine the distribution of these gains at a point in time and over time. As Lazonick (2012a) has argued, in the US economy decades of innovation in high-tech industries has contributed to an inequitable distribution of income and an unstable availability of employment opportunities. It is our contention that, once we have understood China's path to indigenous innovation, we will be able to understand the types of government institutions and business organizations that can ensure that innovation results in the equitable and stable growth that is the essence of sustainable prosperity.

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