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China's Development Path: Government, Business, and Globalization in an Innovating Economy

Yin Li and William Lazonick*

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ABSTRACT

We employ the "social conditions of innovative enterprise" framework to analyze the key determinants of China's development path from the economic reforms of 1978 to the present. First, we focus on how government investments in human capabilities and physical

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* Yin Li is Assistant Professor at the School of International Relations and Public Affairs, Fudan University, and a senior fellow of the Academic-Industry Research Network. William Lazonick is president of the Academic-Industry Research Network and Professor of Economics Emeritus, University of Massachusetts. This essay has its own development path, emerging from a five-year project (2010-2015) on Financial Institutions for Innovation and Development, funded by the Ford Foundation and directed by William Lazonick at the University of Massachusetts. We presented the paper's analytical framework at the Conference on Chinese Ways of Innovation, California State University Northridge, Woodland Hills CA, October 6, 2011. Subsequently, we contributed versions of the paper to the annual meeting of the Business History Conference, Philadelphia PA, March 31, 2012; the annual conference of the Society for the Advancement of Socio-Economics, MIT, Cambridge MA, June 28, 2012; and the Conference on Finance, Business Models, and Sustainable Prosperity, Ford Foundation, New York NY, December 7, 2012. Our approach oriented the discussion at the Beijing Conference on Financial Institutions for Innovation and Development, Institute of Policy and Management, Chinese Academy of Sciences, October 17-18, 2013, organized by Lazonick in collaboration with Leonardo Burlamaqui, Rongping Mu, and Yu Zhou. At that point, Yin Li became focused on researching and writing his PhD dissertation, "Innovation Pathways in the Chinese Economy," at Georgia Institute of Technology, completed in October 2017. Meanwhile, Lazonick worked with Yu Zhou and Yifei Sun on their co-edited book, *China as an Innovation Nation* (Oxford University Press, 2016). A draft of the current version of this paper was presented at the annual meeting of the Business History Conference, Cartagena Colombia, March 16, 2019. In recent years, the collaboration of Lazonick and Li has been supported by the Institute for New Economic Thinking, under the project, "China's Development Path." We thank Kaidong Feng, Tom Ferguson, and Matt Hopkins for comments on drafts of this final version. (Note: Chinese names are written with the family names last.)

infrastructure provided foundational support for the emergence of Chinese enterprises capable of technological learning. Second, we delve into the main modes by which Chinese firms engaged in technological learning from abroad—joint ventures with foreign multinationals, global value chains, and experienced high-tech returnees—that have contributed to industrial development in China. Third, we provide evidence on achievements in indigenous innovation—by which we mean improvements in national productive capabilities that build on learning from abroad and enable the innovating firms to engage in global competition—in the computer, automobile, communication-technology, and semiconductor-fabrication industries. Finally, we sketch out the implications of our approach for current debates on the role of innovation in China's development path as it continues to unfold.

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1. Investment in Productive Capabilities for Economic Development in China

In the last four decades, China has transformed itself from a poor nation to the world's second largest economy—a position it assumed in 2010 (McCurry and Kollewe 2011). In the process, hundreds of millions of people have left behind lives in poverty, while a large and growing middle class, estimated in 2018 at 400 million people, or almost 30 percent of the Chinese population, has emerged (Iskyan 2016; Ho et al. 2019). As in any successful economy, the state has played an indispensable role in China's development by funding and implementing massive investments in human capabilities and physical infrastructure.

Human capabilities include "public services" to staff schools at different levels, health care, research institutes, police forces, fire brigades, and postal systems. The education system is, of course, fundamental. In 1980, 33.1 percent of the Chinese population had no schooling; in 2010 only 6.6 percent. Over these three decades, the population's average years of schooling rose from 3.87 to 7.12 (Barro and Lee 2020). In large part because of government initiatives, China almost quadrupled its research and development (R&D) spending from 0.563 percent of GDP in 1996 to 2.186 percent in 2018 (World Bank 2021). 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. Investments in capabilities and infrastructure tend to be high fixed cost, requiring large expenditures of money over long durations of time before the society realizes the economic benefit of these productive resources as inputs into valued goods and services, consumed domestically and abroad.

Ultimately, China's growth has depended upon the business firms that make use of these government investments in capabilities and infrastructure to produce goods and services that buyers need or want at prices that they are able or willing to pay. The business firms that succeed in national and global competition are those that have developed internal capabilities to produce goods and services that are higher quality and/or lower cost than other firms in their industries. The product markets may be internal to China, with the nation's rapidly growing middle class creating vast opportunities for selling these goods and services. Or the product markets may be in advanced economies, in which case Chinese business firms can progress by upgrading their productive capabilities to move up global value chains. Indeed, as we shall see, a characteristic feature of China's development path has been the extent to which the growth of leading Chinese business corporations has depended on their engagement in production relations on a world scale. Participation in global value chains has enabled Chinese firms to develop capabilities to generate products that are high quality and low cost by global standards.

The process that generates a higher-quality, lower-cost product than was previously available is *innovation*, and it is innovation processes that drive a nation along a path to economic development. Innovation is not simply a good idea but rather a social process that has an economic impact. Innovation is *collective* (it cannot be done all alone) and *cumulative* (it cannot be done all at once). Hence, innovation requires social organization.

Innovation is also *uncertain*. When investments in innovation are made, there is no guarantee that a higher-quality, lower-cost product will be the result. First, the innovating firm faces the *technological* uncertainty of whether it possesses the capability to transform the productive resources under its control into a higher-quality product. Second, the innovating firm faces the *market* uncertainty that, armed with the product that it has developed, it will be able to access sufficient customers to transform, through economies of scale, the high fixed cost of its innovation strategy into low unit cost. Third, the innovation firm faces the *competitive* uncertainty that, despite its investment in the innovation process, a rival business firm, at home or abroad, will generate an even higher-quality product at an even lower unit cost.

At the level of the business firm, innovation depends on three social conditions of innovative enterprise: *strategic control*, *organizational integration*, and *financial commitment*. (Lazonick 2010b; 2015; 2019). We refer to these conditions as "social" because the business firm is a complex social organization in which power, control, decisions, relationships, incentives, skills, and efforts determine the productivity of the transformation of resources (inputs) into goods and services (outputs). Strategy, organization, and finance are the fundamental activities that define a "business model", while control, integration, and commitment imbue the business model with social content.

For innovation to occur in the face of technological, market, and competitive uncertainties, business executives who exercise strategic control over corporate resource allocation must have the abilities and incentives to make strategic investments in innovation. Their abilities depend on their knowledge of how strategic investments in new capabilities can enhance the enterprise's existing productive capabilities. Their incentives depend on alignment of their personal interests with the company's purpose of generating innovative products.

The implementation of an innovation strategy requires the organizational integration of people working in a complex division of labor into the collective and cumulative learning processes that are the essence of innovation. Work satisfaction, promotion, remuneration, and benefits are important instruments in a reward system that motivates and empowers employees to engage in collective learning over a sustained period of time. Integration transforms individual capabilities into organizational capability that can be far more productive than the sum of the results of these individual working in isolation from one another.

For collective learning to cumulate over time, financial commitment must keep the learning organization intact on a continuous basis. For a startup company, personal savings and venture capital can provide financial commitment. For a going concern, retained earnings (leveraged, if need be, by debt issues) are the foundation of financial commitment. The purpose of financial commitment is to sustain investment in the development of the firm's productive capabilities until, through the commercialization of an innovative product, the firm can generate financial returns.

When government agencies invest in capabilities and infrastructure, they can reduce the technological and market uncertainties facing business firms by ensuring them access to an educated labor force, physical resources, and sales outlets without which the innovation strategies of the firms could not succeed. Key to understanding China's decades-long dynamic growth since the economic reforms of 1978 have been the willingness of the Chinese government to fund strategic investments in capabilities and infrastructure while devolving strategic control over resource allocation to the executives of business firms under an array of ownership structures, ranging from state-owned enterprises (e.g., Baowu Steel) to publicly-listed companies with dual-class shares (e.g., Alibaba) to 100% employee-owned companies (e.g., Huawei Technologies) (Lazonick, et al. 2016). The Chinese state has permitted these companies to grow through reinvestment of profits—which is everywhere the financial foundation of the growth of self-sustaining business firms. In many cases and at certain points in their growth, these business firms have then been able to leverage corporate retentions with state-provided loans, which may be massive.

The co-existence of a multitude of ownership structures allows for different types of strategic control in sectors that serve different needs of the economy. In China, critical infrastructure sectors such as highways, railroads, energy, communications, and steel have all remained state-owned, with the government ensuring that more than sufficient capacity would be available to meet the rapid expansion requirements of other sectors of the economy. In those sectors, however, in which there is rapid technological change and the need to react quickly to new market opportunities, the Chinese government has not required that companies be state-owned. Rather it has been willing to devolve strategic control to business firms, with a "hundred flowers" approach to their governance structures.

At the same time, the Chinese government has been proactive in setting up arrangements for foreign direct investment to transfer technology from abroad. Many multinational companies have a large and growing presence in China, producing for the burgeoning Chinese domestic markets or engaging in value-added production of components or end products for global markets. And increasingly, just as has happened in the cases of Japanese and Korean development, companies around the world must be concerned about the emergence of indigenous companies in China that through investment in productive capabilities can compete globally in even the most sophisticated technology industries.

In 2006 the Chinese government made the promotion of indigenous innovation—Zi Zhu Chuang Xin (in Chinese: 自主创新)—central to its Medium- and Long-Term Plan for the Development of Science and Technology (2006-2020) (Liu et al. 2011).[1] We define "indigenous innovation" as the process within a developing nation of improving the quality and lowering the cost of world-leading technologies transferred from abroad. For any

[1] The pioneering academic work on indigenous innovation in China was done by the Qiwen Lu, on a project led by William Lazonick at the UMass Center for Industrial Competitiveness from 1993 to 1998 and the Euro-Asia Centre, INSEAD, from 1998 until Professor Lu's untimely death in August 1999, just after his submission of the final book manuscript *China's Leap into the Information Age: Innovation and Organization in the Computer Industry* to Oxford University Press (published in 2000; see Lazonick 2004). During the late 1990s, Qiwen Lu was in contact with Feng Lu, who was completing his Columbia University PhD dissertation on the reform of Chinese state-owned enterprises. Feng Lu subsequently became a faculty member at Tsinghua University, where, with his student Kaidong Feng, he ran a project on the limits imposed on indigenous innovation of the Chinese policy of "trading market for technology" in the automobile industry. In the spring of 2004, Feng Lu, by that time professor of political economy at Peking University, met with officials at the Chinese Ministry of Science and Technology (MOST) to discuss his report carried out with Kaidong Feng, *The Policy Choice to Develop Our State's Automobile industry with Indigenous Intellectual Property Rights* (see Lu and Feng 2005 for a published version of the report). This report was influential in making "indigenous innovation" central to MOST's Medium and Long Term Plan (Feng 2020, pp. 2-3). For the last decade, William Lazonick and Yin Li have been collaborating with Kaidong Feng on a project on indigenous innovation and economic development in China.

developing country, indigenous innovation is essential to enter global competition in industries that rely on sophisticated technologies.

As has most dramatically been demonstrated by the experiences of Japan and the Asian Tigers, indigenous innovation ultimately provides the foundation for attaining and sustaining a high standard of living (see Lazonick 2004; Lazonick 2009a, ch. 5). In 2010, the indigenous innovation effort became focused on seven strategic emerging industries (SEI) (in Chinese: 战略性新兴产业): energy efficient and environmental technologies; next generation information technology; biotechnology; high-end equipment manufacturing; new energy; new materials; and new-energy vehicles (US-China Business Council 2013).

In May 2015 the Chinese government announced its strategy, Made in China 2025 (in Chinese: 中国制造 2025), to make a concerted effort to enable Chinese companies to compete globally in higher value-added goods and services. The ten targeted industrial sectors are new advanced information technology; automated machine tools and robotics; aerospace and aeronautical equipment; maritime equipment and high-tech shipping; modern rail transport equipment; new-energy vehicles and equipment; power equipment; agricultural equipment; new materials; and biopharma and advanced medical products (Kennedy 2015). Although China substantially toned down the Made in China 2025 plan amid the recent trade war with the United States, Chinese government-business collaborations continue to invest in advancing indigenous innovation. Since November 2020, the Chinese government under President Xi Jinping has intensified the campaign promoting “Self-reliance in Science and Technology” (in Chinese: 科技自立自强) to support indigenous innovations in the “real economy”, from semiconductors to biopharmaceuticals to aerospace engineering (Feng, Li, and Lazonick 2022).

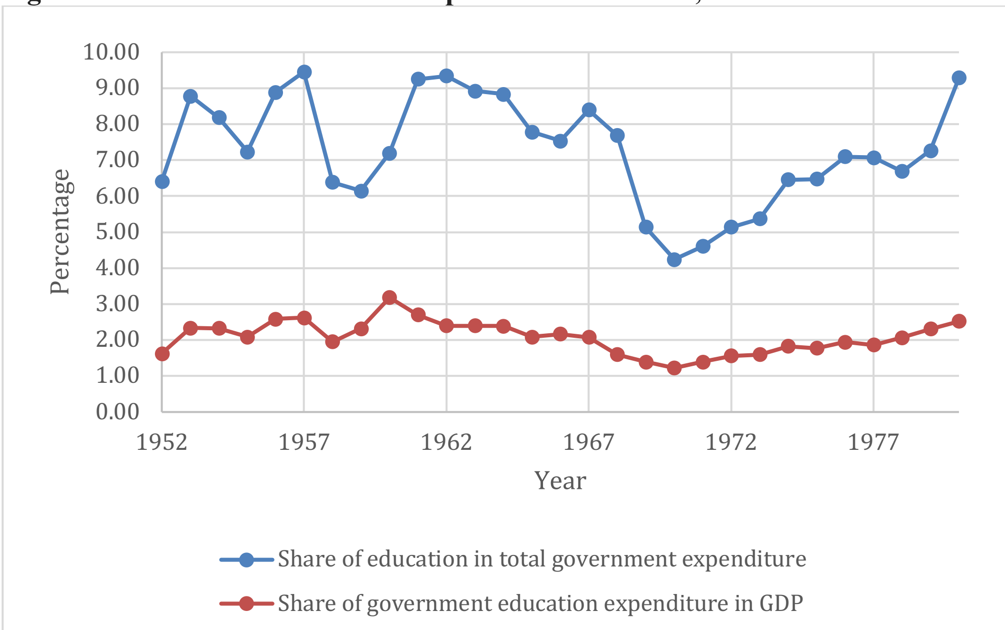
In the next section of this essay, we document investments in capabilities and infrastructure that have provided essential foundations for China’s development path. In the following section, we discuss the main modes of technology learning from abroad—joint ventures with foreign multinationals, global value chains, and experienced high-tech returnees—that have shaped China’s development path. Then in the fourth section, guided by the theory of innovative enterprise, we provide evidence on achievements in indigenous innovation in the computer, automobile, communication-technology, and semiconductor industries. Finally, we sketch out the implications of our perspective for current debates on the role of innovation in China’s development path as it continues to unfold.

2. Investment in Capabilities and Infrastructure

2.1. Investment in education

The foundation of China’s development has been a commitment to the education of a population that represents 18.5 percent of the world total. At the outset of the People’s Republic of China, in 1949, the illiteracy rate was 80 percent (Plafker 2001). From 1952 to 1966, the Chinese government regularly allocated six percent of its expenditures, or about two percent of GDP, to education. The Cultural Revolution (1966–1976), however, undermined this investment process, with education expenditure only recovering to its early-1960s level in 1980 (Figure 1). By 2000, China's illiteracy rate was 15 percent (Plafker 2001).

Figure 1: Government education expenditures in China, 1952-1980



Source: China National Bureau of Statistics 2005.

In 1982, it was written into the Chinese constitution that the government is required by law to provide nine years of free education. The 1982 census showed that 66.5 percent of the adult population had received some formal schooling; in India that figure was only 27.5 percent. Chinese higher education, in contrast, remained underdeveloped, with only 0.9 percent of the population receiving any college education in 1982 (Barro and Lee 2020). Dramatic expansion of Chinese colleges and universities did not occur until the late 1990s, with the annual number of college graduates rising from one million in 2001 to over three million in 2004 and five million in 2008 (*China Statistics Yearbook* 2010, Table 20-9). By 2016, that number had reached over seven million, and by 2020 just under eight million (Textor 2021).

For 1960 to 2010, Table 1 shows results of China's investment in its education system compared with selected advanced and developing economies. In 2010, only 4.0 percent of the Chinese population, 25 years and older, had completed a higher education degree. Nevertheless, given its population size, in 2010 the accumulative number of Chinese who had completed post-secondary education was about 35 million people, up from about 21 million in 2000 and 26 million in 2005. Among the population 15 years and older, the average years of schooling were 8.2 years in 2010, compared with 7.1 years in 2000 (Barro and Lee 2020). At the beginning of the 2020s, China had experienced four decades of phenomenal growth, but it had barely tapped the advanced education potential of its population.

This educational effort provides a partial explanation for why China has been able to grow more rapidly than India over a wider range of industrial sectors. 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 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 the elite, however large numerically, but 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 lower levels in China compared with India.

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

	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 2020

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

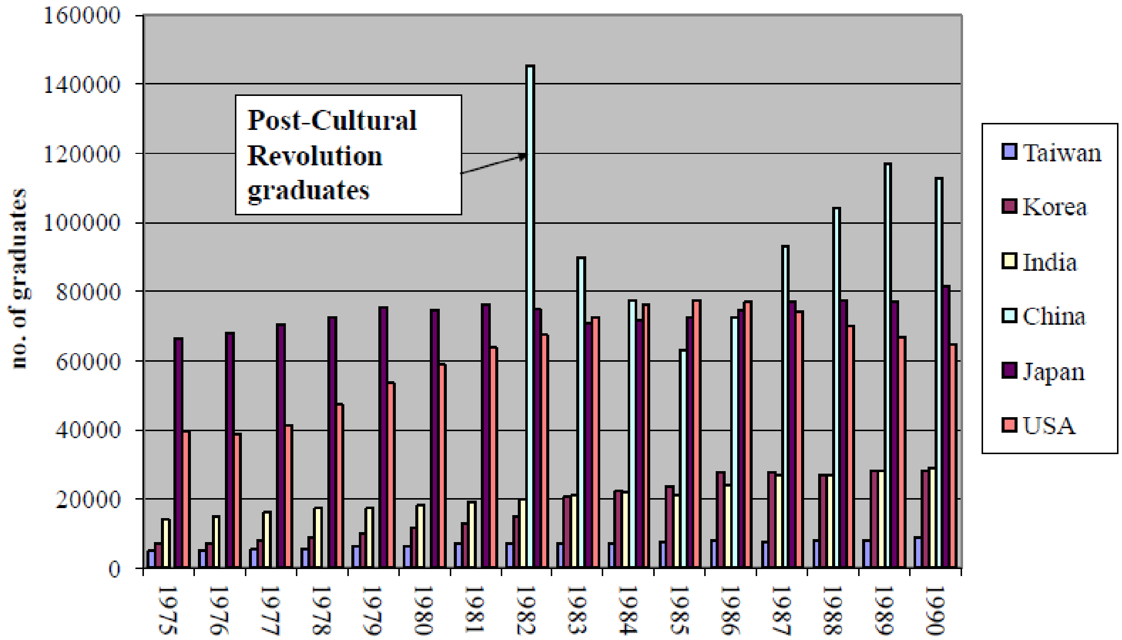
Highest level, educational attainment	China			India		
% who completed level in parenthesis	1980	2000	2010	1980	2000	2010
No schooling	36.0	13.5	8.2	72.5	51.2	42.2
1st level (primary education)	41.3 (17.5)	34.3 (19.8)	29.2 (17.7)	11.3 (4.9)	18.4 (14.2)	19.1 (16.6)
2nd level (secondary education)	21.7 (5.6)	48.0 (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 2020.

At the undergraduate level, as shown in Figures 2 and 3, in the 1980s China emphasized engineering degrees and India emphasized science degrees. Science yields knowledge of the world in which we live, while engineering transforms that knowledge into productive capabilities. This difference in educational focus has placed China in a far better position than

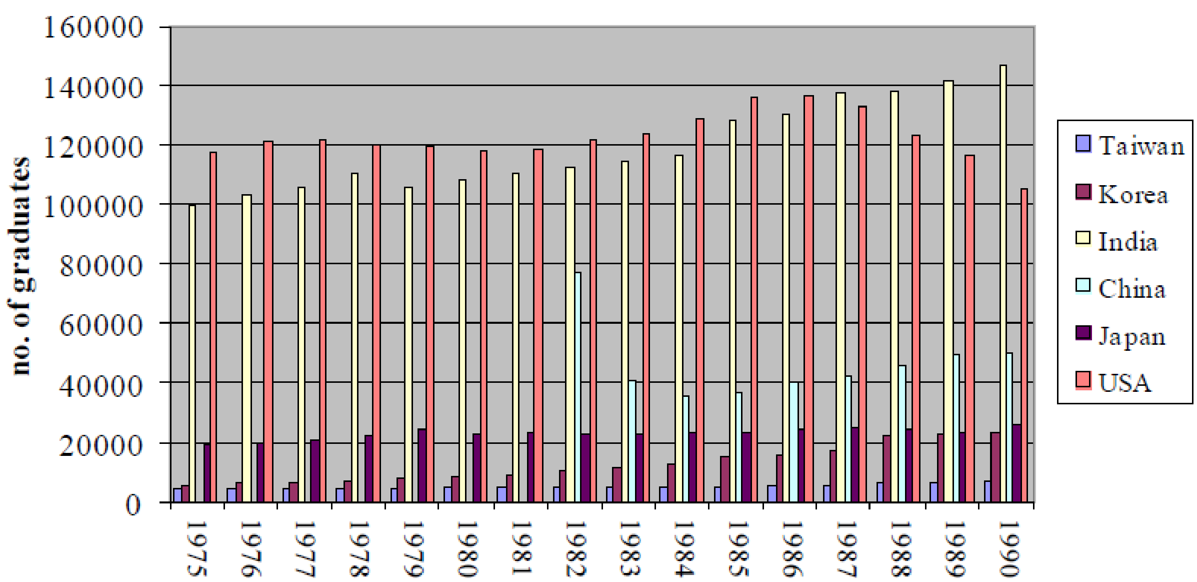
India to absorb technology from the advanced nations and adapt it to indigenous uses (see Lazonick 2009a, ch. 5).

Figure 2: Bachelor's degrees in engineering, selected Asian economies and USA, 1975-1990



Source: National Science Foundation 1993

Figure 3: Bachelor's degrees in natural sciences, selected Asian economies and USA, 1975-1990



Source: National Science Foundation 1993

2.2. Investment in the S&T system

To engage in learning from advanced economies and develop indigenous capabilities, a nation must invest in science and technology (S&T), including those capabilities needed to absorb and further develop knowledge transferred from abroad (Kim 1997; Berggren et al. 2011). The rate, direction, and effectiveness of organizational learning in the most populous nation in the world entail interactions among government agencies, business firms, and household units—or what Lazonick (2021) has called "the investment triad" (see also Lazonick 2022).

In the 1950s, China adopted the centralized planning system of the Soviet Union to build its S&T system (Simon 1989). Long-term planning for S&T development was 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, and automobiles, among other areas. On the eve of the Cultural Revolution, China had approximately 120,000 R&D personnel working in a research system dominated by industrial ministries and the Chinese Academy of Sciences. This S&T system could claim considerable achievements, such as the development of an atomic bomb and the launching of satellites.

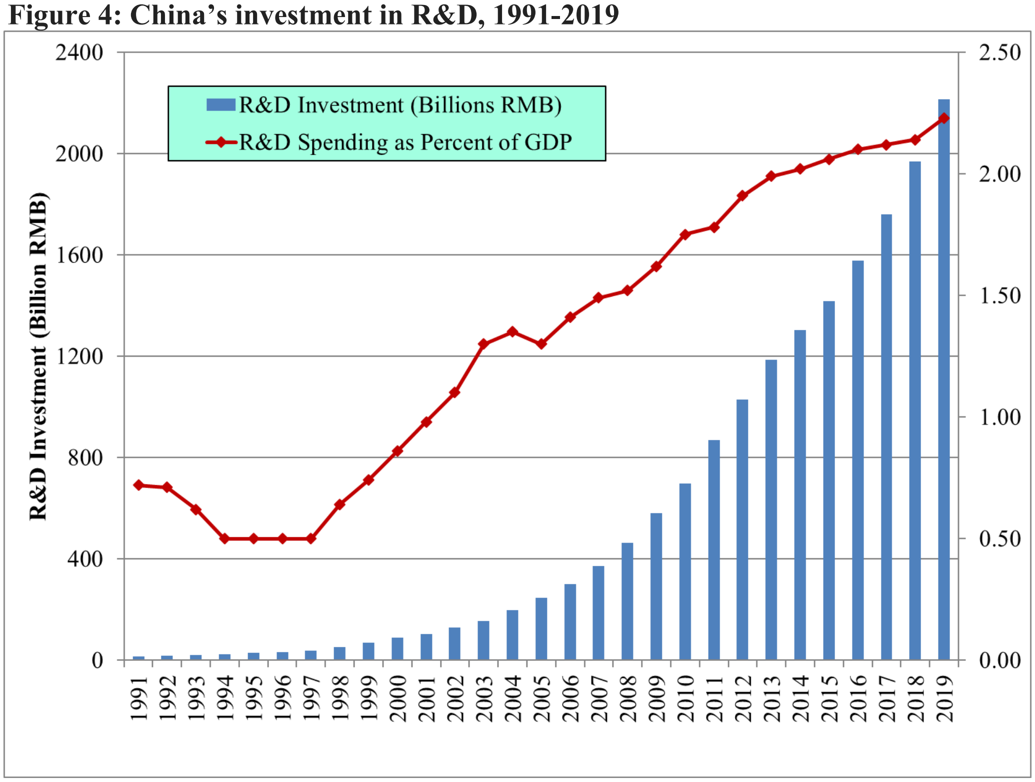
Throughout the 1980s and 1990s, the reform process fundamentally restructured the S&T system. Beginning in the early 1980s, the Chinese state cut back on funding of research institutes and universities, abolished the industry-specific ministries, and transformed government research institutes into independent enterprises or parts of SOE groups. By 1998, the State Council ordered the transformation of 242 national-level research institutes into technology services agencies and enterprises (Liu and White 2001). A new system emerged, with the Chinese state launching a number of S&T programs, including Key Technologies R&D Program (1982), High Technology R&D Program (863 Program) (1986), Basic Research Program (973 Program) (1997), and Innovation Fund for SMEs (1999). Coordinated by the Ministry of Science and Technology (MOST) and Natural Science Foundation of China (NSFC), these programs and agencies implemented the new system for public funding of R&D. By the late 1990s, when continuous economic growth gave the Chinese state ever-increasing budgets to re-fund the S&T sector, the government also decided that the central actors in the new innovation system would not be industrial ministries, but rather universities, public research institutions, and business enterprises.

The Chinese universities had limited roles in carrying out research in the pre-reform S&T system. Except for a few of the most prestigious universities, such as Tsinghua, Peking and Chinese University of Science and Technology, Chinese universities were organized for teaching. In the late 1990s, the state launched "985 Project" and "211 Project", pumping resources into about one hundred universities and transforming them into research-oriented institutes. The primary public research institute, Chinese Academy of Sciences, went through a series of similar transformations to reduce its size but enhance its research profile. In the 2000s, the state made further investments in programs such as the "Thousand Talents Project" to attract high-quality researchers to return to China. In 2017, the Ministry of Education merged "985 Project" and "211 Project" into a new "Double First-Class University Plan" with the goal of developing a selected number of Chinese universities and their individual departments into world-class institutions by the end of 2050.

For business enterprises, the two-decades long transition in the S&T sector had two important consequences. First, the rapid decline of pre-reform institutions in the 1980s pushed state scientists and institutes to engage with the business sector, either through spinning off companies or by scientists becoming entrepreneurs. The pre-reform S&T system gave birth to the first generation of Chinese non-government S&T companies (Lu 2000; Zhou 2008b; Section 4 below). Second, business firms became the primary actors in R&D through absorbing the knowledge and, in many cases, personnel of the reformed government research institutes and investing in internal R&D. In the late 1990s, the business sector surpassed the government sector as the largest funder of R&D. By the 2000s, business spending on R&D accounted for more than 70 percent of China's R&D expenditure.

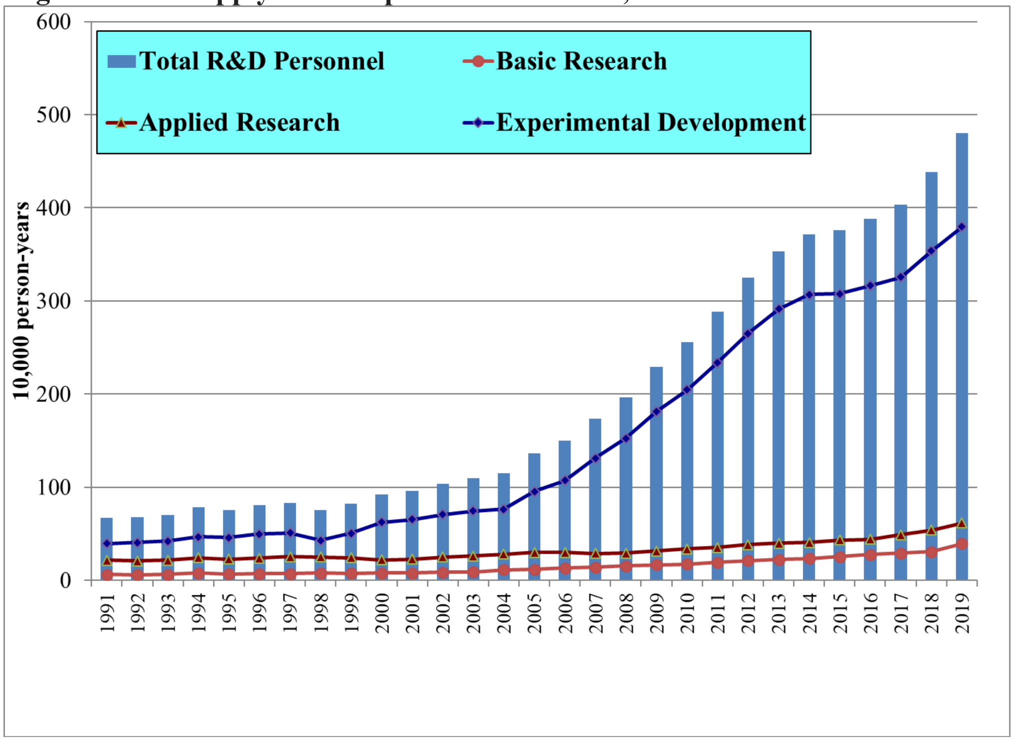
Figures 4 and 5 show the trends in China's R&D investment and the R&D workforce from 1991. As shown in Figure 4, R&D investment stagnated in the 1990s while the S&T system was undergoing restructuring. From the late 1990s, R&D increased rapidly in terms of both absolute value and a proportion of GDP as the state aggressively reinvested gains from economic growth into the S&T system. Since 2015, China has spent more than two percent of GDP on R&D, a standard achieved by only a small number of industrialized nations. Figure 5 reveals the other side of the story: the huge increase in the R&D workforce, driven by the allocation of people to "experimental development" research, which is primarily employment in business R&D to transform knowledge developed elsewhere into industrial processes and commercial products.

Figure 4: China's investment in R&D, 1991-2019



Source: *China Statistical Yearbook*, Chapter 20, various years

Figure 5: The supply of R&D personnel in China, 1991-2019



Source: *China Statistical Yearbook*, Chapter 20, various years

2.3. Investment in infrastructure

To be productive, an educated and experienced labor force needs to be supported by adequate physical infrastructure. The Chinese state has undertaken investment in infrastructure since the founding of the People's Republic, but its strategy has changed dramatically over the years. In the first three decades of the PRC, the state adopted Soviet-style planning to jumpstart the country's industrialization, including railroad construction, steel manufacture, and petroleum refining, among other critical infrastructural inputs. During the 1950s, the Soviet Union provided aid to China's development plan with the construction of some 150 industrial enterprises, the provision of tens of thousands of visiting Soviet advisors, and a massive transfer of technical knowledge and blueprints (Zhang et al. 2006).

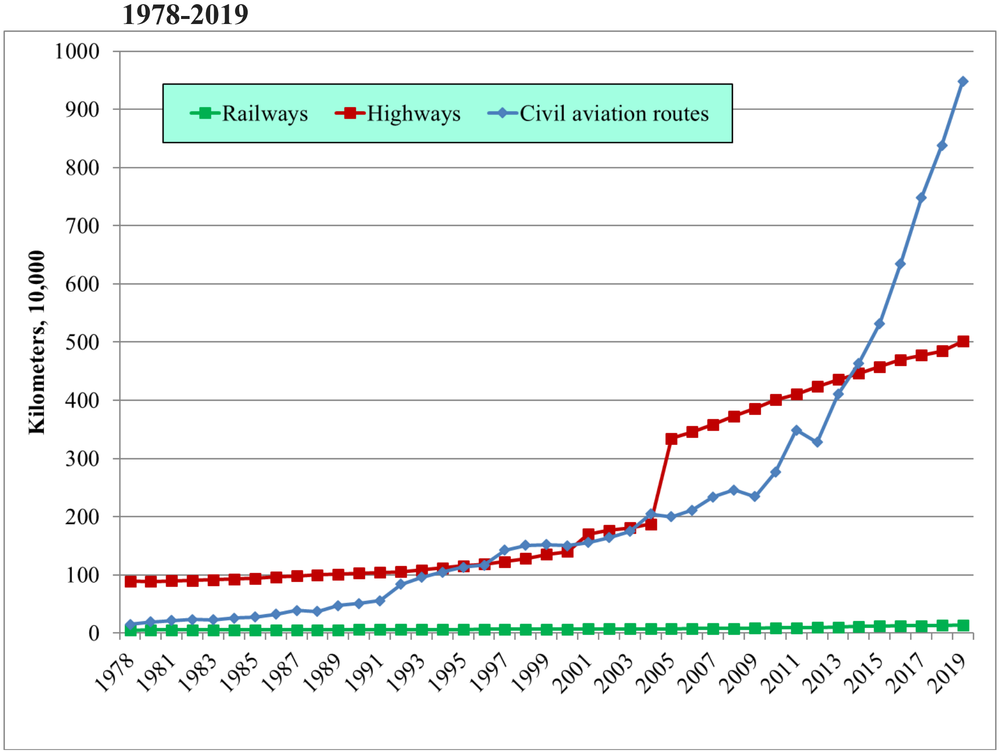
By the end of 1970s, however, there were widespread shortages in the planned economy, with scant resources available for renewed infrastructure investment. Throughout the 1980s, the combined investment in three main categories of infrastructure—transportation, telecommunication, and electricity—accounted for less than five percent of GDP. Annual investment in telecommunication infrastructure, which would underpin the upcoming information age, averaged a meager 0.2 percent of GDP.

Subsequently, however, through reforms in governmental authority and the banking system, China transformed itself into a juggernaut of infrastructure investment. In the 1980s, a series of reforms in the fiscal and tax systems altered the relationship between the central and local governments (Oi 1992). With the central government permitting localities to retain part of tax revenue, while tying their bureaucrats' career prospects to regional economic growth, Chinese regional governments had the funds and the incentives to promote the development of their local economies (Walder 1995). Throughout the 1990s, sub-national governments made up to 70 percent of total public expenditures in China (World Bank 2002).

Next, to channel China's deep pool of savings into the hands of developers, the reform established a set of mechanisms to finance infrastructure investment. In 1993, the government established China Development Bank (CDB). which raised funds for giant development projects including the Three Gorges Dam and Pudong International Airport, in addition to thousands of projects in infrastructure, communication, transportation, energy, and basic industries (Sanderson and Forsythe 2012). For the financing of infrastructure investment at the regional level, local governments have used revenues collected from land sales, through an arrangement in which real estate developers or local government investment agencies use the land as collateral to borrow heavily from CDB and other state banks to invest in the conversion of farmland to real estate and industrial uses (Lan 2021).

The result of these reforms was an infrastructure boom from the 1990s. While the economy maintained almost double-digit growth, the combined annual rate of growth of investment in transportation, telecommunication, and electricity was regularly above six percent of GDP, and during the 2000s this rate of growth was frequently above eight percent (Naughton 2007, 345; *China Statistics Year Book* 2000; 2005, 2010, Section 16). A major component of Chinese investment in infrastructure has been the expansion of the transportation network of railways, highways, and airways (see Figure 6).

Figure 6: Expansion of China's system of railways, highways, and airways, 1978-2019

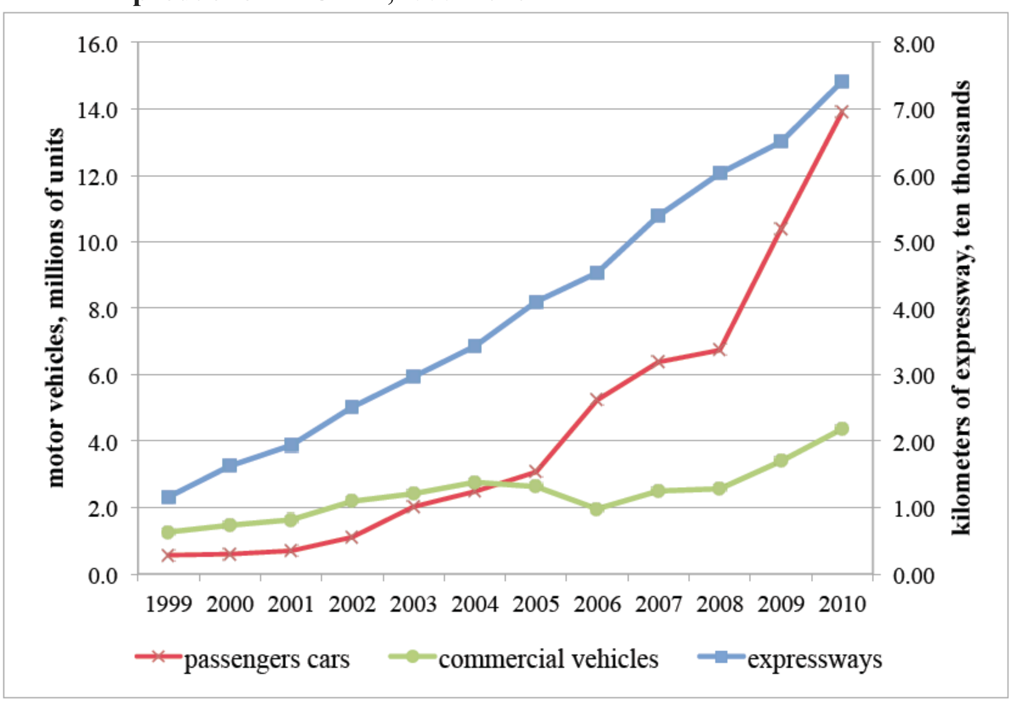


Source: *China Statistics Year Book* 2018, Table 16-4, plus previous issues.

From the 1990s, China invested heavily in its railway system, more than doubling track in operation from 57,800 kilometers in 1990 to 139,000 kilometers in 2019, including constructing the longest high-speed rail network in the world (Ministry of Transportation 2020; see also Liu et al. 2016). The Ministry of Railroads, which was solely responsible for planning, financing, and constructing the railroads, was dissolved in 2013 and replaced by the state-owned China Railway Corporation (reincorporated as China State Railway Group, Ltd in 2019). China has also become a world leader in container shipping ports (Miller 2022). Among the world's top 50 ports by shipment volume, 15 were Chinese in 2019, up from eight in 2004 (World Shipping Council, 2022).

In building the transportation network, the government's major focus has been the highway system, with a huge road-building boom occurring in the 2000s. As charted in Figure 7, the building of highways was largely in anticipation of the boom in Chinese automobile production, almost all of which continues to be for sale on domestic markets. Begun in 1990, China's National Trunk Highway System (NTHS) is an expansive expressway network, encompassing "five vertical" and "seven horizontal" national trunk highways (Li and Shum 2001). By the end of 2019, China's expressway network totaled 149,600 kilometers, making it the largest expressway system in the world (Ministry of Transportation 2020).

Figure 7: Expressway kilometers in operation and annual motor vehicle production in China, 1999-2010



Sources: *China Statistical Year Book*, 2011, Table 16-4; International Organization of Motor Vehicle Manufacturers, various years.

In basic industries that provide inputs for industrialization, a number of Chinese state-owned enterprises (SOEs) emerged as the world's largest producers through the restructuring of the SOE sector in the 1990s. Early reforms emphasized the introduction of incentives for SOEs to improve their productive performance and permits for the entry of non-state-owned firms as competitors. Until 1993, SOEs were not allowed to go bankrupt. Subsequently, SOE managers had to figure out how to remain financially viable. By the end of the 1990s, the government promoted the consolidation of state-owned industry around the largest enterprises, with massive closures of small- and medium-sized SOEs (Steinfeld 1999; Nolan 2001).

Steel, as a key example, experienced rapid expansion of production capacity and concentration among large SOEs. 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.[2] With the exception of Jiangsu Shagang Group, a township and village enterprise (TVE) founded in 1975 that was privatized in 2001, all of the major companies in the Chinese steel industry are SOEs (Tang 2010).

The state-owned steel industry has provided a fundamental input on an enormous scale for China's urbanization and industrialization. The largest sources of demand for steel have been building and infrastructure construction, accounting in 2017 for 68 percent of overall steel production, followed by machinery (19 percent) and automobiles (eight percent) (Rimnac and Pfatschbacher 2019). As we discuss below, China has emerged as the world leader in motor-vehicle production, measured in the number of units produced. The rapid growth of this sector has been dependent on the Chinese government investments in highway expansion and steel production documented above.

China's massive investment in physical infrastructure has been undertaken in an economy undergoing rapid institutional and organizational change. The older system that emphasized centralized planning in resource allocation has gradually been dissolved and replaced with networks of regional governments, business enterprises, and commercial banks that jointly make investment decisions. China's success in investing in infrastructure that supports rapid economic development reflects the central government's strategic ability to commit resources to large development projects while devolving dynamic decision-making to regional governments and business enterprises, both state-owned and non-state-owned.

3. Technological Learning

In the previous section, we have summarized the historical process of China's investment in human capabilities and physical infrastructure. The Chinese state has supported mass education since the early stage of the PRC, took the lead in the transformation of the S&T knowledge base from the 1980s, and has maintained a high rate of investment in physical infrastructure. In general, the Chinese state has devolved control over operational decisions to lower-level organizations, including regional governments, business enterprises, and non-government entities, while maintaining the ability to make strategic decisions concerning transformational projects through its control over a few large institutions, including the

[2] These data are from the World Steel Association, Steel, *Statistical Yearbook*, various years (including 2011 data).

world's largest state-owned banks and SOEs. Besides this integration of Communist Party strategy with a nationwide organizational structure for implementation, this devolution of decision-making power also permits superior organizational integration within local entities by enabling their executives to reward employees up and down the hierarchy for their contributions of skill and effort to the work processes in which they are engaged.

A less-developed nation that seeks to embark upon a path of indigenous innovation needs to first close the gap with global technological frontiers by learning from advanced economies. In China's development path, the country's technological learning has been greatly facilitated by the process of globalization, characterized since the 1980s by the intensification of the cross-border movement of products and people. In this section, we summarize how China has absorbed industrial technology and knowledge transfers from the advanced economies through Sino-foreign joint ventures, global value chains, and reverse brain drain.

3.1. Sino-foreign joint ventures

A primary Chinese strategy for industrial upgrading in the 1980s and 1990s was the creation of Sino-foreign joint ventures (JVs) with the goal of "Shichang Huan Jishu (in Chinese: 市场换技术)", or "Trading Market for Technology" (TMFT). The TMFT strategy, as the name indicates, has given foreign companies access to Chinese domestic markets in exchange for sharing their advanced technologies with Chinese partners (Sun 2002; Lu and Feng 2005; Naughton 2007, 357; Feng 2020, ch. 4). Wholly foreign-owned enterprises have been permitted in China since 1986, but in important industrial sectors such as automobiles and telecommunications, a Sino-foreign joint-venture has been the only legitimate way for a foreign company to invest in China.[3] The Chinese partner of the JV is usually a large SOE. China officially dropped the TMFT policy upon joining the World Trade Organization (WTO) in 2001, although China was still asked to eliminate implicit TMFT requirements in the US-China Trade Deal in 2019.

TMFT was partially driven by the desire to develop domestic capabilities that would enable import substitution. Prior to TMFT, China emphasized the importation of capital equipment to expand domestic production, spending some USD8 billion importing manufacturing equipment between 1972 and 1982 (Li and Huang 2001, 648). Imported production lines did not, however, significantly improve domestic technology capability and market access, as domestic firms did not engage in learning about how to attain the productive potential of the imported technologies. As the Chinese market opened to imports, superior foreign products rapidly gained market share. The number of cars imported into China, for example, increased from only 1,401 in 1981 to 105,775 in 1985 (*China Automotive Industry Yearbook* 2003, 26).

TMFT was the Chinese government's response to foreign competition (Feng 2020, ch. 4). In 1978, the automobile industry began 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

[3] In the automobile industry, as discussed below, the first exception to this rule has been the case of Tesla, which in 2018 was given permission to build its factory in Shanghai (McDonald 2018).

managed the state-owned automobile industry at the time, wrote a report arguing for the benefits of JV. In this report, Rao Bin, 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 [increase] the manufacturing localization of parts and components" (quoted in Teng 2008). Around the same time, in negotiations to set up a telecommunication-equipment JV, State Councilor Jinfu Zhang spelled out TMFT, as he wrote: "[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 1983, was Shanghai Bell to manufacture telecommunication equipment. It involved a large SOE factory in Shanghai and Belgium's Bell Telephone Manufacturing (BTM) Company. In the next year, in automobiles, Shanghai Volkswagen was established. Soon, JVs were set up in most manufacturing sectors. It has been estimated that between 1978 and 2000 more than 80 percent of foreign direct investment went to JVs, with an emphasis on automobiles, chemicals, and electronics (Chen and Yue 2002). Early JVs such as Shanghai Bell and Shanghai Volkswagen were given almost a complete monopoly in their market segment. Later, the entry barriers in several sectors such as automobiles, machinery, and chemicals were maintained, protecting JVs from domestic and international competition up until the mid-2000s (Feng 2010, 75-78).

The JV agreements negotiated between Chinese and foreign companies have included complex and broad-ranging technology transfers, including production, R&D, sub-contracting, marketing, after-sale services, and local human resource training (Mu and Lee 2005). Among them, production localization is the main form of technology learning that was implemented through meeting local content requirements set by the Chinese government. 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 it achieved 70 percent within five years (Segal and Thun 2001). Shanghai-Bell started by assembling imported modules, and later moved to the manufacture of sophisticated components, such as integrated circuits (ICs). Through these arrangements, the Chinese partners in the JVs hoped to learn to master the production process as well as the technologies embedded in them. The other channel of knowledge flow, although less visible, was through engineers trained by the foreign partners in JVs. After gaining experience at JVs, many Chinese engineers then moved on to higher salaries and more challenging positions at emerging indigenous companies (Mu and Lee 2005; Feng 2020, ch. 5).

In terms of import substitution and deployment of production capacity, TMFT was a tremendous success. In 2009, China became the world's largest manufacturer of passenger cars, by number of units produced, surpassing Japan, and since 2016 China has produced more cars than the next four largest car manufacturing nations combined. Until 2005, Volkswagen, through its JVs with FAW and SAIC, was the leading producer of passenger cars in China, but since then has been challenged and in some years surpassed by General Motors through its JV with SAIC.

The Chinese partners in JVs, however, achieved limited success in mastering the technologies embedded in production processes and transforming them into innovation capabilities. The critical problem for the Chinese was that the foreign partners secured strategic control of the JVs because of their knowledge of technology, management, and markets. The foreign firms were able to exclude Chinese managers and engineers from organizational learning processes, with the purpose of preventing the Chinese partners from becoming future competitors (Feng 2020).

3.2. Global value chains

In parallel to TMFT, China simultaneously followed the strategies of the Asian Tigers in export promotion. China's export factories were initially dominated by the migration of labor-intensive industries from Hong Kong, Taiwan, and Southeast Asia. Yet, as China became integrated into the global economy, industrial upgrading along the global value chain presented another opportunity for technological learning. The Chinese information-and communication-technology (ICT) industry is a major beneficiary in this process.

An indication of the importance of ICT to China's global competitiveness and its integration into global value chains can be seen in data on China's trade with the United States in "advanced technology products" (ATP) (Tables 3, 4, 5 and 6). In 2000, one year before joining the WTO, China's share of US ATP imports was 5.5 percent, while Japan's was over three times as high at 17.8 percent. By 2002, China's share had risen to 10.2 percent (see Table 3), while Japan, although still the leading nation for US ATP imports, saw its share fall to 12.1 percent. By 2010 China's share had skyrocketed to 32.6 percent, with Mexico now in second place at 13.8 percent and Japan now in third place with 6.6 percent. Since then, US ATP imports from China have represented over one-third of all US ATP imports, except for 2019 and 2020, when China's share fell to 27.5 percent and 27.1 percent, due to the adverse impact of the US-China trade war.

Table 4 shows that US ATP exports to China also rose substantially in the 2000s. In 2000, China took 2.2 percent of the global ATP exports of the United States, but that more than doubled to 4.6 percent in 2002, still less than half the percentage of US ATP exports to Japan. But the Chinese share increased to 7.8 percent in 2010 and a peak of 10.8 percent in 2018—at that point more than twice the percentage to Japan. The recent US-China trade war reduced US ATP exports to China from USD39.2 billion in 2018 to USD30.7 billion in 2020, although, even then, China took 10.2 percent of all US ATP exports.

In 2017 China accounted for three-fifths of all US ICT imports from around the world. In 2016-2018, 44 to 47 percent of US ATP exports to China were in aerospace, although that proportion fell to 31 percent in 2019 and 14 percent in 2020 because of the trade war and the problems with the Boeing 737 MAX plane (Lazonick and Sakinç 2019). In 2020, China was the recipient of 25 percent of all US flexible manufacturing equipment exported worldwide, representing just over USD5 billion. While aerospace exports to China declined in 2019 and

2020, electronics became the leading ATP category for US exports, increasing from USD7 billion in 2018 to USD9 billion in 2019 and USD11 billion in 2020.[4]

Table 3: Shares of US Advanced Technology Products (ATP) imports by top ten nations in 2020, 2002-2020

	2002	2004	2006	2008	2010	2012	2014	2015	2016	2017	2018	2019	2020
U.S. ATP imports, USDbillions	196.1	238.5	290.8	331.2	354.2	396.0	421.5	434.9	428.9	464.6	497.4	496.6	492.2
	percent of annual total												
China	10.2	19.2	25.0	27.6	32.6	35.7	36.7	35.7	34.4	36.8	34.9	27.5	27.1
Mexico	8.3	9.3	10.6	12.2	13.8	12.5	10.8	12.1	12.4	11.6	12.1	12.3	12.1
Taiwan	6.8	5.4	4.8	4.2	4.3	3.8	3.5	3.3	3.3	3.3	3.4	4.8	5.9
Ireland	6.7	5.6	4.9	5.3	5.3	4.8	4.2	4.3	5.1	5.1	5.5	5.8	5.9
Malaysia	7.7	7.6	8.6	6.1	6.1	3.7	4.4	5.0	5.9	5.4	5.2	5.2	5.4
Germany	4.1	4.0	3.9	3.5	2.9	3.4	4.1	4.1	3.9	3.9	4.4	5.0	5.2
Vietnam	0.0	0.0	0.0	0.1	0.2	0.3	1.2	2.1	2.5	2.4	2.1	4.2	4.9
Japan	12.1	10.0	8.9	8.1	6.6	6.3	5.6	5.1	4.9	4.7	4.6	4.9	4.2
South Korea	7.1	7.0	4.7	7.5	4.9	4.9	4.0	3.6	4.1	3.8	3.9	3.7	4.0
Thailand	1.6	1.9	2.5	2.4	2.2	2.4	2.9	2.6	3.0	2.4	2.3	2.3	2.9

Source: US Census Bureau, various years.

Table 4: Shares of US Advanced Technology Products (ATP) exports by top ten nations in 2020, 2002-2020

	2002	2004	2006	2008	2010	2012	2014	2015	2016	2017	2018	2019	2020
U.S. ATP exports, USDbillions	180.6	201.5	252.6	270.1	273.3	304.5	335.9	343.1	345.8	353.7	369.4	364.2	300.9
	percent of annual total												
Mexico	7.0	8.2	7.4	7.3	10.0	9.4	10.9	11.7	11.4	11.1	11.3	11.4	11.9
China	4.6	4.7	7.0	6.4	7.8	6.3	9.2	9.9	9.7	10.1	10.6	9.3	10.2
Canada	9.6	10.1	9.3	10.0	10.1	8.1	9.1	8.7	8.2	8.6	8.8	8.6	8.8
Germany	5.2	4.6	5.1	6.4	6.1	3.6	4.2	4.1	3.9	4.4	5.0	5.4	6.0
Japan	9.3	9.0	7.7	6.5	5.7	5.5	5.2	4.9	5.2	5.0	5.1	5.4	5.2
Netherlands	4.0	4.5	4.0	4.5	3.5	2.9	3.5	3.7	3.7	3.6	3.8	4.0	4.5
UK	5.9	6.0	5.0	5.2	4.4	3.8	4.5	4.7	4.9	4.3	4.8	4.3	3.9
Taiwan	5.1	4.9	4.1	3.7	3.8	2.8	3.2	3.6	3.7	3.2	2.9	3.2	3.9
South Korea	6.0	5.1	5.6	3.8	4.0	3.6	3.5	3.8	3.9	4.4	3.8	3.3	3.8
France	4.1	4.6	4.0	4.0	3.9	3.2	3.3	3.6	4.0	4.5	4.7	4.8	3.6

Source: US Census Bureau, various years.

Much of the increased imports from China to the United States and exports from the United States to China over the past two decades represent the growth of global value chains in high-tech fields. A substantial portion of this trade represents value-added exports from China to the United States by US companies operating in or outsourcing to China. As shown in Tables 5 and 6, about 90 percent of all US ATP imports from China have been ICT; for example, Apple's imports of its smartphones manufactured by Foxconn in China are in the ICT category.

[4] Note that changes in reporting of Advanced Technology Products data by the US Census Bureau prevent us from updating these ATP data to 2021. The data used to construct Tables 3, 4, 5, and 6 were previously downloaded from the US Census Bureau ATP webpages and are available from the authors.

Table 5: US Advanced Technology Product (ATP) exports to and imports from China as percent of China's distribution across ATP categories, 2016-2020

	2016		2017		2018		2019		2020	
	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports
U.S. ATP trade with China, USDbillions	33.4	147.6	35.7	171.1	39.1	173.8	33.9	136.7	30.8	133.5
Advanced Technology Products	Percent distribution of U.S. trade with China by ATP category									
Biotechnology	2.5	0.1	2.7	0.1	2.7	0.2	6.7	0.2	6.0	0.4
Life Science	10.3	1.8	10.4	1.5	9.9	1.5	11.5	1.8	13.7	2.3
Opto-Electronics	1.4	3.9	1.7	3.1	1.9	3.1	1.7	3.0	1.5	2.3
Information & Communication	14.4	90.0	12.7	90.9	10.2	90.4	9.9	90.8	10.6	91.2
Electronics	18.0	2.6	17.1	2.6	17.7	3.0	26.5	2.4	36.1	2.4
Flexible Manufacturing	8.3	0.7	8.3	0.8	9.9	0.8	11.5	0.7	16.4	0.7
Advanced Materials	0.7	0.2	0.8	0.2	0.7	0.2	0.8	0.2	0.8	0.1
Aerospace	43.7	0.6	45.7	0.6	46.7	0.7	31.0	0.8	14.4	0.5
Weapons	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.1
Nuclear Technology	0.7	0.1	0.6	0.0	0.2	0.0	0.4	0.0	0.4	0.0
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Source: US Census Bureau, various years.

Table 6: US Advanced Technology Product (ATP) exports to and imports from China as percent of world ATP category, 2016-2020

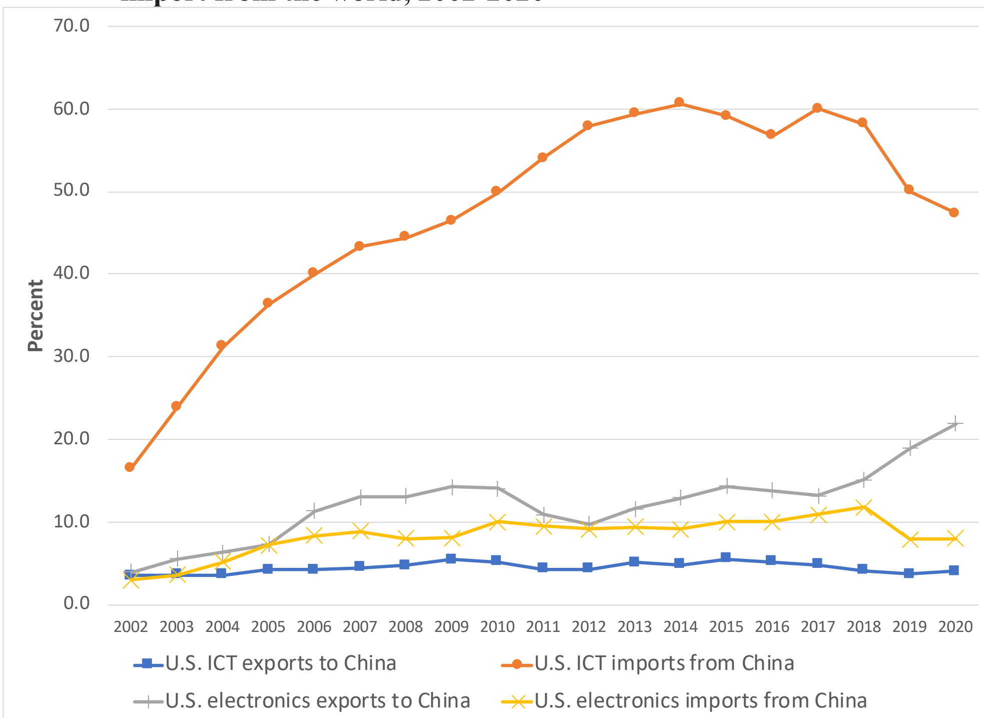
	2016		2017		2018		2019		2020	
	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports
U.S. ATP trade , USDbillions	345.8	428.9	353.9	464.3	368.1	497.4	364.2	496.6	300.9	492.2
Advanced Technology Products	China as percent of U.S. ATP category									
Biotechnology	4.7	0.7	5.0	0.7	5.0	0.7	9.4	0.5	7.9	0.9
Life Science	11.9	5.7	12.6	5.7	12.5	5.3	12.3	4.6	13.5	5.5
Opto-Electronics	10.3	22.4	12.8	23.1	13.9	25.4	11.5	17.2	10.3	12.1
Information & Communication	5.2	56.8	4.8	60.0	4.1	58.2	3.7	50.1	4.0	47.3
Electronics	13.8	10.0	13.2	10.9	15.1	11.8	18.9	7.9	21.9	8.0
Flexible Manufacturing	16.8	9.4	14.7	9.8	19.2	9.8	22.3	5.2	25.2	6.7
Advanced Materials	9.7	14.7	10.0	14.5	9.1	13.3	8.7	9.1	9.3	7.0
Aerospace	10.9	1.8	12.4	2.1	13.0	2.1	7.6	1.9	5.4	1.6
Weapons	0.1	16.9	0.1	15.3	0.1	15.1	0.0	13.8	0.1	15.5
Nuclear Technology	21.4	3.4	22.9	1.5	11.7	3.3	11.9	0.7	11.6	0.4
TOTAL	9.7	34.4	10.1	36.8	10.6	34.9	9.3	27.5	10.2	27.1

Source: US Census Bureau, various years.

Basically, even during the trade war, China remained dependent on microelectronic devices and equipment manufactured in the United States (see Khan 2020; Lazonick and Hopkins 2021), while over 90 percent of its ATP exports to the United States were ICT products. Figure 8 shows the growing importance of US ICT imports from China, rising from 17 percent of all US ICT imports in 2002 to a peak of 61 percent in 2014 and falling back to 46 percent in 2020. Figure 8 also shows the rising trend of US electronics exports to China, from four percent in 2002 to 22 percent in 2020.

China's growing importance in ATP trade reflects in large part the technological upgrading that it has achieved through participation in global value chains. A classic example is the industrialization of China's Pearl Delta Region (Breznitz and Murphree 2011, ch. 5). Lacking industrial and R&D infrastructure initially, the Pearl Delta Region pursued a development strategy driven by FDI, integration into the global supply network, and moving up through original equipment manufacturer (OEM), original design manufacturer (ODM) to original brand manufacturer (OBM). As the test ground of Deng Xiaoping's open-door policy, the Pearl Delta Region became the main location for absorbing FDI from areas of China's diaspora. Hong Kong and Taiwan investment brought in flows of finance, experience in OEM production, and connections within global value chains. Combined with inexpensive labor, it jumpstarted industrialization in the region.

Figure 8: US information-and-communication technology (ICT) and electronics exports to and imports from China, as percent of US exports to and import from the world, 2002-2020



Source: US Census Bureau, various years.

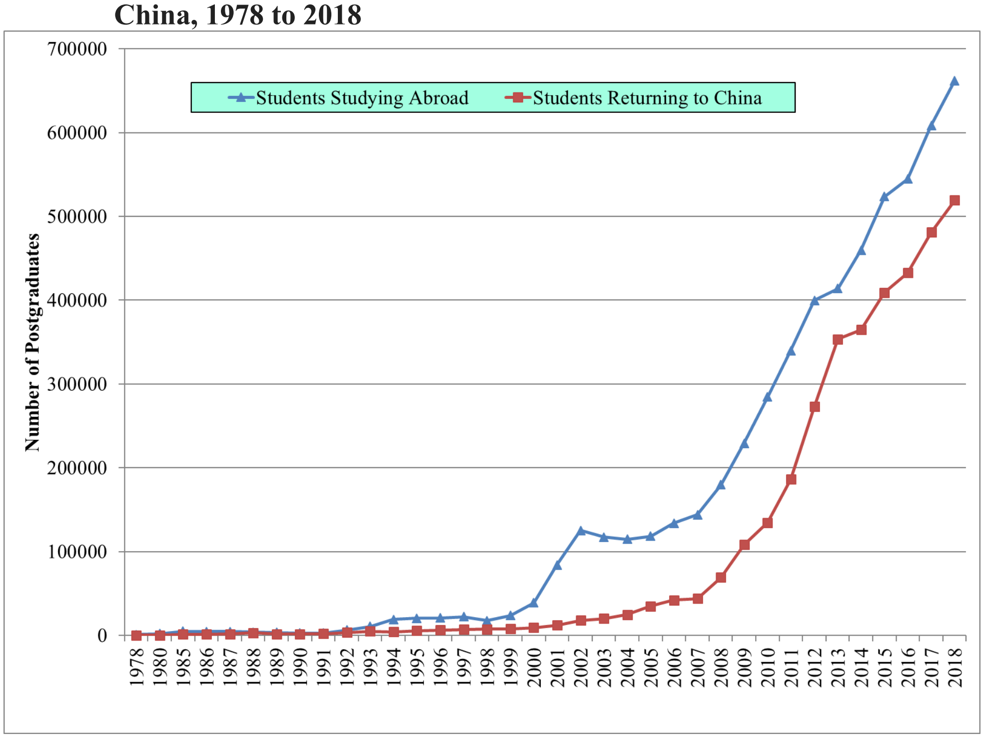
As documented in Breznitz and Murphree's (2011, 181-193) case study of the uninterrupted power supply (UPS) industry, a typical upgrading process for companies in the region started with the simplest assembly operations. As the producers learned from their multinational corporation clients, they gradually increased the amount of research they performed. When the quality of the products reached the point at which customers came to trust a Chinese producer, it then earned the right to be a globally competitive supplier with high degrees of freedom in design and branding. After three decades of upgrading, the Chinese UPS companies moved from low-profit-margin assembly operations to become independent brands in the forefront of technological innovation.

By the 2010s, a growing number of Chinese firms in the ICT industry had emerged as global competitors. The most notable examples are Chinese smartphone makers, including Xiaomi, Oppo, Vivo, and Oneplus, that have built global brands by integrating key components, such as Qualcomm chips and Android operating system, provided in the global value chains. Nevertheless, the most successful Chinese technology firms not only benefit from upgrading through global value chains but also rely heavily on accessing the large Chinese market to develop their innovation capabilities (Zhou 2008a, 2008b; Li 2022). We shall further illustrate the dynamics of global value chain and local market access in the processes of indigenous innovation, discussed in section 4.

3.3. Reverse brain drain

Since the 1950s, China's investment in an educated labor force has laid the foundation for the nation's development. In making these investments, however, like other less-developed countries, China faced the "brain drain" problem that large numbers of its most promising college graduates left the country to seek graduate education and work opportunities abroad. In the 1960s, 1970s, and 1980s South Korea and Taiwan experienced substantial brain drains, with the United States as the favored destination (Lazonick 2009a, ch. 5). So too, since the 1980s, there have been large-scale outflows of college-educated labor from China and even more so, from 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 2018



Source: *China Statistical Yearbook*, various years, Chapter 20

The United States invites the international migration of college-educated people through the availability of non-immigrant H-1B and L-1 work visas (allocated mainly to college graduates) as well as employment-based preferences in the allocation of permanent resident visas (Lazonick 2009a, ch. 5; Lazonick et al. 2022).[5] Since China does not permit its nationals

[5] An H-1B visa enables a company (US 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 (US 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.

to hold dual citizenship, the H-1B and L-1 nonimmigrant visas provide often invaluable opportunities for Chinese with higher educations, some of which may be advanced degrees from US universities, to access substantial high-tech work experience in the United States without giving up Chinese citizenship.

During the decade of the 2000s, 46.5 percent of all H-1B visas and 36.9 percent of all L-1 visas went to Indians, but Chinese were second in H-1B visas with 6.3 percent and 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). Of the 188,123 H1-B visas issued in 2019, Indians received 69.9 percent, followed by Chinese with 15.1 percent, and Mexican 1.5 percent. Of the 76,988 L-1 visas issues in 2019, 23.8 percent went to Indians while Chinese received 6.6 percent, following closely behind nationals of the UK, Brazil, and Mexico (US Department of State 2019).

As can be seen in **Error! Reference source not found.**, in the 2000s there was a sharp increase in the number of Chinese postgraduate students who had studied abroad and then returned to China. More generally, China has been the beneficiary of the phenomenon of "reverse brain drain" or "brain gain" that economies such as South Korea and Taiwan experienced from the late 1980s (Saxenian 2006; Lazonick 2009b, ch. 5). These returnees have brought knowledge and experience of advanced technology as well as global contacts back to China. In Beijing and Shanghai, more than 80 percent of the returnees who start a business hold graduate degrees from an overseas institution (Kaufman 2003; Zhang 2008).

The return of entrepreneurial Chinese with advanced degrees and work experience 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 US 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 2008a; Zhou and Hsu 2011). China's Internet giants of the 2000s 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 Chinese students abroad were *not* funded by the Chinese government), the central government adopted a strategy of competing for talent on the international labor market. In 2000, President Jiang Zemin made public statements about China's need to compete on the global market for talent—specifically to lure back its own people from abroad (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; 2016).

During the 2000s returnee-founded companies were highly concentrated in the ICT sector, in which new ventures can be easily inserted into well-defined global production networks. The very existence of these global networks means that returnees' global contacts and knowledge are highly valued (Zhou 2008b; 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 extends well beyond the ICT industry. Returnee scientists and engineers have founded indigenous Chinese solar companies such as Suntech Power and Trina Solar (Hopkins and Li 2016).

In this section, we have summarized the venues and processes for China to engage in technological learning from advanced nations. We have focused on Sino-foreign joint ventures, global value chains, and reverse brain drain—knowledge-transfer mechanisms operating at substantial scale that have contributed to the formation of a broad industrial knowledge base and the creation of industry-specific productive capabilities, including the accumulation of scientific, engineering, and management skills, in China. We have not analyzed the controversial channel of industrial espionage because, given the importance of the legitimate modes of international technology transfer that we have documented, there is little evidence that intellectual-property theft has had a significant influence on China's development path.[6] In addition, China's highly publicized strategy to acquire advanced foreign technology through M&A has borne little fruit: Recent attempts to acquire American semiconductor companies, such as Lattice, Micron Technology, and Western Digital Corporation, have all been blocked by the US government.

The key to understanding the rise of China as a formidable global competitor across a range of technologically advanced industries is the triadic investments in productive capabilities by Chinese household units, government agencies, and business firms. China's experience of technological learning has greatly benefited from the process of globalization, which brought global production to the country's doorsteps and allowed its citizens to travel, study, and work abroad. Such learning would not be possible however, without the state's financial commitment to investments in education, infrastructure, science & technology, and industrial capabilities, all of which contribute to the absorptive capabilities of individual workers and companies.

[6] Most of the evidence on China's technology theft come from two Trump administration reports: Office of the United States Trade Representative (2018); White House Office of Trade and Manufacturing Policy (2018)

4. Indigenous Innovation

China has had varying degrees of success in learning about advanced technologies across its industrial sectors. In part, this variation exists because industries differ in terms of technology, markets, and competition. In addition, when the Chinese government invests in capabilities and infrastructure, it ultimately relies on innovative enterprises to engage in learning processes. Technological learning is inherently a part of the indigenous innovation process, which, to repeat, we define as improving the quality and lowering the cost of world-leading technologies that had previously been transferred from abroad. Indigenous innovation depends on the three social conditions of innovative enterprise: *strategic control*, *organizational integration*, and *financial commitment*. In this section, by documenting the history of the computer, automobile, telecommunication-equipment, and semiconductor industries, we summarize how the social conditions of innovative enterprise have supported, to a greater or lesser extent, indigenous innovation as the increasingly defining characteristic of China's development path.

4.1. Computer electronics: China's leap into the information age

In the 1980s, a number of the newly established *minying* (in Chinese: 民营) S&T companies became China's pioneers in engaging in indigenous innovation. The *minying* companies were a new category of business enterprise that emerged out of the economic reforms, encompassing SOE-spinoffs, "collectively owned" companies, and privately owned firms, all of which operated outside direct state control. The word *minying* literally means run by the people, as opposed to state-run. Against a background of perceived technological backwardness in China, the innovative successes that *minying* S&T companies 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-electronics 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 SOEs. 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 Peking 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). The three companies were "collectively owned"; 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

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

Legend, the spin-off's executives had "full autonomy in managerial decision-making, financial budgeting, and employee recruitment" (Lu 2000, 65). It was the power to exercise strategic control over the allocation of a firm's resources by executives with the abilities and incentives to invest in innovation, and not "well defined property rights", that was critical to indigenous innovation in China.

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 system 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 manufacturing facilities and distribution channels.

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 an enormous 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 constraint in computers at that time of insufficient memory for Chinese ideographic characters. 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.

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 SOEs. But, as a distinctive feature of China in the 1980s, the state largely restrained itself from extracting rents from these successful *minying* companies, allowing them to reinvest profits for further growth. For example, the group of engineers who founded Stone 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 0.02 percent. Even Founder, which had very close relations with Peking University, retained the majority of its earnings (Lu and Lazonick 2001).

The control over revenues and earnings gave managers of the *minying* enterprises a critical financial foundation for investing in innovation. As early as the 1990s, Founder was able to spend more than RMB15 million per year on R&D, covered by internal funds. 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 strategic control over financial resources, 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 factories were limited to fulfilling production quotas. Stone, Legend, and Founder all established nationwide distribution networks. In particular, Legend integrated before- and after-sales services in its distribution channels and made these services available all over China. This distribution network in turn permitted the company to access a larger market and to learn from its customers, both of which are critical to the innovation process.

To sustain their rapid growth, the *minying* 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 systems until 2000 and remains one of China's major high-tech conglomerates. Stone was adversely affected by the departure of its founder and general manager in 1989, and in the 1990s the company evolved into a diversified conglomerate which no longer focused on high-tech.

The early growth and success of the *minying* computer-electronics companies was based on indigenous innovation. These companies benefited from state investment in the legacy S&T system, but they emerged as indigenous innovators by improving on these technologies and generating higher-quality, lower-cost products to access markets in ways that the SOEs had been unable to do. The key to their success was the autonomy from government direction or intervention in becoming self-sustaining enterprises that could execute, and in these successful cases, profit from an innovation strategy. In these autonomous *minying* companies, strategic control was given to scientists-turned-managers with intimate knowledge of technology who allocated the companies' resources to investments in products, R&D, and other productive capabilities at a scale and with an intensity unmatched by state companies. Managerial autonomy to reward, motivate, and retain employees permitted these companies to lure key technologists from the state sector and integrate them into the new organizations. Meanwhile, with the central, regional, and local governments exercising self-restraint in appropriating the gains from innovative enterprise, these companies, having received seed funding from the state sector, were able to retain revenues for further financial commitment to innovation.

The emergence of the social conditions of innovative enterprise in China in the 1980s was not serendipitous. Defining characteristics of the government's economic reforms were permission for Chinese citizens to form autonomous business enterprises and permission for the enterprises they founded to tap into the financial, personnel, and S&T resources provided by government agencies as foundations for their subsequent growth as independent business firms. As we show in the following summaries of the evolution of the automobile, communication-equipment, and semiconductor industries, the willingness of the government to grant business firms managerial autonomy and access to publicly funded physical infrastructure and human capabilities have been critical conditions for indigenous innovation.

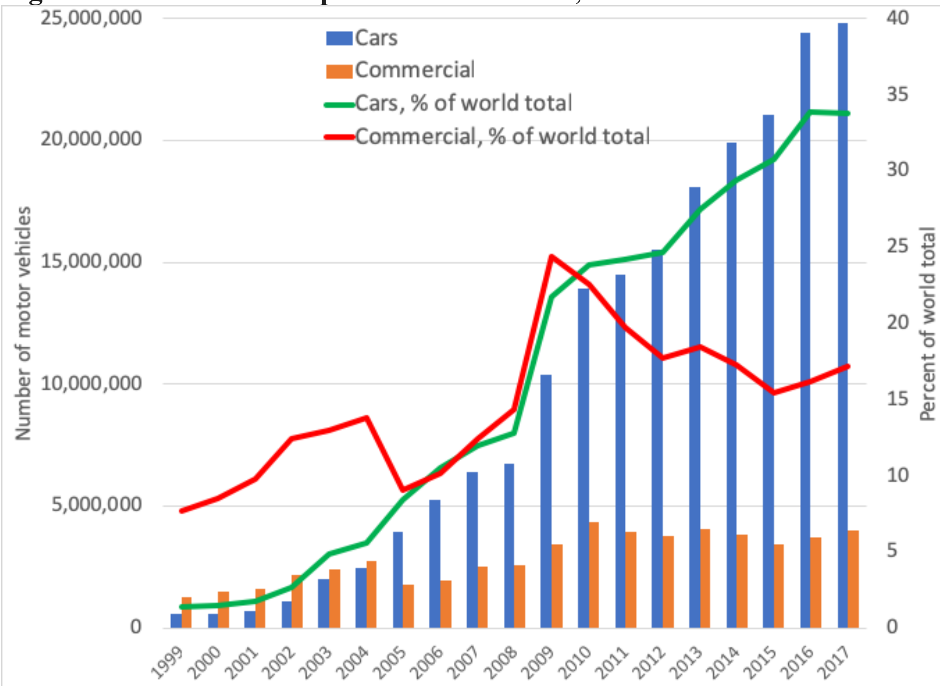
4.2. Automobiles: From TMFT to indigenous innovation and beyond

While permitting the emergence of *minying* companies, the Chinese government continued to invest in SOEs in competitive sectors. In the 1980s and 1990s, under the TMFT policy, the formation of Sino-foreign joint ventures (JVs) was the primary national strategy for industrial upgrading of SOEs (Lu and Feng 2005; Lu 2006). Drawing on Feng (2010; 2016; 2020) and Li (2022), we consider the histories of the automobile and communication-equipment industries, both of which were heavily influenced by the TMFT policy.

In 1978, for the first time, the Chinese government initiated talks with Germany's Volkswagen with the goal of establishing a JV automobile enterprise. This discussion led to the 1983 JV agreement between Shanghai Automobile Industry Corporation (SAIC) and Volkswagen, and the establishment of Shanghai Volkswagen in 1984. 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. In 1982, before the establishment of the first joint venture, the entire Chinese industry produced merely 4,000 vehicles. By 2000, the nation produced 605,000 passenger cars (see Figure 10). In 2013, China's production of cars was 18.1 million, or 27.6 percent of the world total of 65.5 million. In units, in 2013 China's production surpassed the *combined* total of Japan (8.2 million), Germany (5.4 million), and the United States (4.4 million). Right behind the United States was South Korea with 4.1 million cars produced, a big leap from 1.6 million 15 years earlier, but not close to China's progress over this period. Of the 19 million cars produced in China in 2013, just over one million were exported, mainly to low-income nations, with Algeria, Iraq, Russia, Iran, and Chile as the top five markets (Canis and Morrison 2013, 1-2).

Figure 10: Motor vehicle production in China, 1999-2017



Source: International Organization of Motor Vehicle Manufacturers, various years.

In 2017, China produced 24.8 million cars, 33.8 percent of world production, while also manufacturing 4.0 million commercial vehicles, 17.1 percent of world production. While the Chinese car industry cannot yet compete with the Japanese, Germans, Americans, and Koreans in terms of quality, it has already surpassed the car industries of India (4.0 million cars) and Russia (1.3 million), which have far longer histories of automobile manufacture. In comparative-historical perspective, the Indian and Russian car industries have lacked the organizational learning at the enterprise level that car companies operating in China have been acquiring since the 1980s.

China's massive expansion of productive capacity was driven by a strategy that emphasized production localization and economies of scale (Segal and Thun 2001; Lu and Feng 2005). 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 production localization of the Santana in 1989, 70 percent in 1990, and 92 percent in 2000 (Feng 2010, 98). By 1998, when SAIC established a second JV with General Motors, it took only two years to achieve 40-percent localization of the newly imported Buick model.[8] 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 appeared in the list one year later.

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

Yet the pursuit of the localization strategy and manufacturing efficiency came at a cost. While the automobile JVs grew bigger than ever, they generally lacked the innovation capability to develop new car models. None of the JV automobile companies systematically developed new models over the TMFT period.[9] 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 (Feng 2010).

While a JV partnership tends to include joint product-development projects in the legal agreement, in reality such projects are poorly implemented because of both lack of interest from the foreign partners and incompetence of Chinese SOEs. The co-development of a new car model, Santana-2000, as part of the Shanghai-Volkswagen JV project illustrates the difficulties of product development at JVs. 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 ten 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 the neglect of product-development activities, automobile JVs remained dependent on technology transfers from foreign partners to upgrade their product lines. In 2005, the Chinese government's introduction of its "Indigenous Innovation" policy began to place political pressure on the automobile JVs to generate "innovation" by delivering new car models. However, the lucrative JV business model was difficult to give up (Feng 2010, 143). By ceding strategic control over technology development to foreign partners, Chinese state-owned automobile companies failed to accumulate capabilities to engage in indigenous innovation.[10]

Although TMFT was the dominant industrial policy, the JV business model did not dominate in all industrial sectors. Into the early 2000s, the main markets for passenger cars in China were mid-sized vehicles for government agencies and taxis. Geely, Chery, BYD and other non-governmental carmakers, operating outside the JV system, had emerged at the end of the 1990s, targeting the household market, enabled by the growth of the Chinese middle class, with budgets that in the 2000s favored the purchase of smaller, more fuel-efficient cars that catered to a wide variety of consumer tastes. While from the late 1990s the Chinese government permitted domestic entry of Chinese-owned carmakers, national policy did not promote these non-governmental companies. These companies grew by developing lower-cost automobiles that significant proportions of car-buying households viewed as value-for-money to become viable competitors to multinational and JV firms.

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

In 2013 three indigenous non-SOE companies, Geely with 554,000 cars produced in China, BYD 511,000, and Chery 459,000—ranking #13, #14, and #15 respectively in car production in China—accounted for a combined 7.8 percent of the Chinese total.[11] By 2017, as shown in Table 7, Geely had shot up to the #8 position, with over 1.3 million vehicles produced and 5.1 percent of production in China, while Chery's 2.1 percent share was declining. Although BYD's share declined from 2.6 percent in 2013 to 1.9 percent in 2017, the company has now emerged, as we discuss below, as China's leading EV manufacturer.

Table 7: Top 15 producers of motor vehicles in China in 2017 and shares of total motor vehicle production, 2016 and 2017

		Vehicles produced in China		Share of Chinese production		
Rank in 2017	Company	2016 units	2017 units	2016 percent	2017 percent	National base
1	Volkswagen	3,896,310	4,041,179	14.3	14.3	Germany
2	SAIC	2,564,786	2,866,913	9.4	10.2	China
3	GM	1,876,256	2,005,500	6.9	7.1	USA
4	Changan	1,715,871	1,616,457	6.3	5.7	China
5	Nissan	1,320,687	1,506,343	4.9	5.3	Japan
6	Dongfeng	1,315,490	1,450,999	4.8	5.1	China
7	Honda	1,209,400	1,441,928	4.4	5.1	Japan
8	**Geely**	511,054	1,338,882	1.9	4.7	China
9	BAIC	1,343,682	1,254,483	4.9	4.4	China
10	Hyundai	1,829,922	1,182,548	6.7	4.2	South Korea
11	Toyota	1,073,372	1,145,414	3.9	4.1	Japan
12	Great Wall	1,094,360	1,041,025	4.0	3.7	China
13	Ford	1,008,425	923,450	3.7	3.3	USA
14	**Chery**	631,454	605,331	2.3	2.1	China
15	FAW	557,174	592,688	2.0	2.1	China

Source: International Organization of Motor Vehicle Manufacturers, 2016 and 2017.

While Chery produced more cars in 2016 than Geely, its sales subsequently remained stagnant, while for 2017-2020 Geely's sales averaged 1.26 million units per year. Geely has its origins in a company founded by Shufu Li in 1986 to produce refrigerator parts and in the 1990s became the second largest light motorcycle producer in China. In 1997 Li mobilized all his available financial resources to launch Zhejiang Geely Holding Group Co. to enter the motor vehicle industry (Feng 2020, 133). Geely had secured possession of a government license to produce automobiles after acquiring a state-owned car company that had failed. In 2000, with an eye on China's prospective entry into the WTO, the Chinese government officially permitted car production by new entrants that were non-state-owned (Feng 2020, 45).

When indigenous companies like Chery and Geely began producing passenger cars in the early 2000s, they were low cost but also low quality. As Kaidong Feng (2020, 56) puts it:

[11] These rankings are based on data available on the website of the International Organization of Motor Vehicle Manufacturers.

> Common consumers could easily tell the visible gaps in terms of design, technology and manufacturing qualities between the products of newly emerging firms and those of Sino-foreign JVs. However, they were still persuaded by the much lower price. Particularly, a lot of consumers would have not been included in the market if there had not been a rise of these challengers.

But Feng (who, with Professor Feng Lu, closely followed the progress of Chery and Geely in real time) goes on to point out that these new entrants also distinguished themselves from the JV firms by the frequency with which they upgraded their products:

> In contrast [to the JV firms], the newly emerging firms implemented a strategy of "small steps, quick run" (in Chinese: 小步快跑). It was not just a product strategy but also a technological learning strategy. At their early stage of capability construction, they took the high frequency of technological upgrade as a pattern to interact with customers and industrial partners. By doing so, they could learn through interactions, absorb knowledge from rival products and remedy the faults they had ever made. And the customers were also attracted by the "visible" progress demonstrated by the new product campaigns of innovative firms (Feng 2020, 57).

Competition from the indigenous innovators then forced the incumbent SOEs to innovate as well, which they could only do through engaging in technological learning (Feng 2020, 58-62). As part of this dynamic, which Feng (2020, ch. 5) calls the "re-emergence of engineers", the indigenous firms were able to draw engineering talent from the incumbent SOEs, including FAW and Hafei, attracting key people by offering them strategic control over the allocation of a car company's resources to investments in collective and cumulative learning processes (Feng 2020, 133). Shufu Li created a top-management system in the Geely group's subsidiaries in which engineering professionals exercised strategic control over technology decisions while a family member or representative retained control over administrative matters (Feng 2020, 146).

Geely began manufacturing passenger vehicles in 2002, surpassing half a million vehicles in both production and sales in 2013 and two and a half that amount annually in 2017-2020 (CarSalesBase 2022a). In the process, Geely expanded the range and increased the quality of its offerings. In 2010, it acquired Volvo's passenger car division (Volvo Trucks remains an independent Sweden-based company, in which Geely purchased an 8.2 percent stake in 2017) (Hellstrom 2017; Oberholzer-Gee et al. 2019). In 2012, as one mode of entry into the clean-technology field, Geely acquired London Taxis International, renaming it London Electric Vehicle Company (Reynolds 2018). In 2017, Geely struck a deal with Malaysia-based DRB-Hicom to purchase a 49.9 percent share of Proton, the Malaysian car company, and a 51 percent share of Lotus, the iconic UK-based racing-car manufacturer (Beckwith 2017). In 2018, Geely Chairman Li became the largest shareholder of Germany-based Daimler, spending USD9 billion for a 9.7 percent stake, in another move to give Geely access to advanced technology (Shirouzu and Taylor 2018).

In 2016, with its Volvo subsidiary in Sweden, Geely founded Lynk & Co to produce a range of passenger cars, focused on SUVs, with advanced internet connectivity and a technology platform for shared ownership of a vehicle. In 2020, Lynk & Co sold over 175,000 units in China and was on track for about 222,000 in 2021 (CarSalesBase 2022b). By 2019, SUVs had already accounted for 52 percent of Geely total sales in China (Autocar Pro News Desk 2020). The Geely group announced its most advanced SUV, Xinghue L, in July 2021 (Geely Global Media Center, 2021).

Meanwhile, with Chinese innovation in electric-vehicle batteries and its enormous domestic car market, the Chinese automobile industry is moving beyond indigenous innovation to become a global leader in new electric vehicles (NEVs), which includes both battery electric vehicles (BEVs) and plugin hybrid electric vehicles (PHEVs) (Teece 2019; Graham et al. 2021; Finamore et al. 2021; Herrer 2022). In 2021, NEVs were less than two percent of all cars in use in China but, with 3.3 million NEVs sold in China during the year, they were 15.7 percent of all car sales, up from 5.8 percent in 2020 (Randall 2022). The rapid growth of NEVs has been supported by Chinese government policy, announced in October 2019, to ban the sale of all-gasoline vehicles by 2035. At that point, the target is for 50 percent of cars sold in Chine to be NEVs (including fuel-cell powered EVs as well as BEVs and PHEVs) and 50 percent non-plugin hybrids.

According to tabulations compiled by electrive.com for 2021, the ten leading companies selling NEVs in China were BYD, 593,745; Tesla, 473,078; Hongguang Mini EV, about 400,000; Ora, 135,028; GAC Aion, 123,660; Geely, 100,126; Xpeng, 98,155; Nio, 91,425; Volkswagen (MEB), 70,625; and Neta, 69,674. The numbers for both BYD and Geely include PHEVs, while sales of the other eight were all BEVs (Randall 2022; for other data, see Cheng 2022). In the first half of 2022, BYD sold 640,748 NEVs (of which 326,236 were BEVs), a 15.4 percent share of the worldwide NEV market, surpassing Tesla's 564,873 NEVs (all BEVs), a 13.6 percent share (Kane 2022c). Key to BYD's rapid growth as an EV producer is its vertical integration into battery innovation as well the design and fabrication of many of the chips it uses in its cars (China Money AI 2021; Kothari 2022; Cox 2022).

Tesla stands out as the first wholly owned foreign car company to be permitted by the Chinese government to manufacture in China (McDonald 2018), obtaining preferential loan rates from four state-owned Chinese banks to build its first car factory outside the United States (Ren 2019). On January 7, 2020, Tesla opened Shanghai Gigafactory 3 for production of its Model 3, less than one year after construction of the plant had begun (Bloomberg 2020). In permitting Tesla to manufacture in China without a JV with a Chinese company, Chinese EV-industry policy has moved well beyond TMFT. The current goal, toward which great progress has been made, is to transcend indigenous innovation to attain global technology leadership. Tesla's presence in China has accelerated innovative competition in EVs among a host of China carmakers, including Nio's battery-swapping technology (Ramey 2022) and the Wuling best-selling microcar, Hongguang Mini EV (Kane 2022a). China's development path means that in the third decade of the twentieth-first century, China can make use of Tesla for the nation's EV transition without being dependent on the US company.

Tesla's entry has also reinforced China's leads in EV charging infrastructure and EV batteries. Tesla has invested in a Shanghai factory to produce superchargers and by November 2021 had installed 8,000 in China with plans for three times more over the next three years (Sudhanshu 2021). An industry consortium, China Electric Vehicle Charging Infrastructure Promotion Alliance (EVCIPA), coordinates parties investing in charging stations and provides advice to the Chinese government (Hove and Sandalow 2019; Shirley 2022). EVCIPA has reported that about 440,000 new charging stations were installed in 12 months from October 2020, and there were over one million in place by September 2021 (Kane 2021).

Finally, a condition of China's deal with Tesla is that it purchase all the batteries for its China-made cars from CATL, which has now emerged as the world's leading manufacturer of EV batteries (Zhang and Munroe 2021; Bradsher and Forsythe 2021). Before its entry to China, Tesla had sourced its batteries from Japan's Panasonic and Korea's LG Energy Solution. By the beginning of 2022, CATL had built a battery plant in Shanghai to supply Tesla, with its Gigafactory 3 just three kilometers away (Kane 2022b). CATL has now expanded into Germany and has announced plans to invest in EV battery production in the United States (Mihalascu 2022; Steitz and Klayman 2022)

4.3. Telecommunication equipment: from local competitors to global innovators

Along with the automobile industry, the telecommunication-equipment sector was one of the early adopters of the TMFT strategy. As early as 1983, Shanghai-Bell was created as the first Sino-foreign JV in the manufacture of telecom switches. Between 1984 and 1993, major state-owned telecom-equipment companies established JVs with multinationals. By pursuing an aggressive strategy of product localization, leading telecom JVs grew rapidly over the 1990s. By 2000 Shanghai-Bell became the largest provider of telecom switches in the world (Feng 2020, 92-95).

In contrast to the protection given to the state-owned carmakers, the Chinese government permitted non-state domestic as well as international competitors in the telecom-equipment sector by removing most of the entry barriers during the 1980s. The main driver for the liberalization of the telecom-equipment sector was to satisfy the enormous demand for telecom services, funded by the central and local governments as critical infrastructure. The decentralized structure of the Chinese telecom market, in which grassroot operators made independent procurement decisions up until 1998, provided opportunities for domestic manufacturers to grow. In effect, the Chinese telecom market was a dual-track system during the 1980s and 1990s, in which multinational corporations, including BTM, Nortel, Nokia, Motorola, Lucent, NEC, Ericsson and Siemens, dominated the high-cost, high-quality urban markets through JVs under TMFT, while the indigenous manufacturers gained market shares in the low-cost rural markets (Li and Feng, 2022, 14-16).

Among the local telecom-equipment manufacturers that entered the fierce competition in the 1980s, two *minying* start-ups, Huawei and ZTE, emerged to dominate the Chinese telecom market by the end of the 1990s. Originally founded as Zhongxing Semiconductors, ZTE was established in Shenzhen in 1985 by Weigui Hou as a spinoff from a state-owned 691 factory of the aerospace ministry in Xi'an, Shanxi Province. Initially targeting advanced semiconductor technologies, Hou sensed the opportunity in the market for telecom switches, raised funds from a Shenzhen SOE and a Hong Kong trading firm, and quickly turned Zhongxing into a telecom-equipment company in 1986. By 1993, to resolve conflicts between its three shareholders, Hou reorganized the firm as ZTE, jointly owned by his management team, 691 factory, and the state-owned Shenzhen Guangyu Industries. This model of "state ownership and *minying* operation" gave Hou substantial strategic control over management decisions. ZTE's structure of state ownership and managerial control was formalized through a stock market listing on the Hong Kong Stock Exchange in 1997.

Huawei was founded in 1987 as a *minying* trading company that imported private branch exchange (PBX) switches from Hong Kong. Its initial investment of RMB21,000 came from six founders' personal savings. But the founder and manager, Zhengfei Ren, made the decision to develop and manufacture switches in-house, a high-risk strategy that caused the subsequent departures of the five other founders. By 1990, to save on wages while retaining employees, Ren started an employee stock ownership program (ESOP) by selling Huawei's shares to its employees at the price of one yuan per share. Over the next thirty years, Huawei's ESOP evolved with changing corporate laws in China, but its key implication remains unchanged: it has kept Huawei off the stock market, enhancing the retention of Huawei's profits as its prime source of financial commitment. Ren retains a right to veto board decisions, despite holding only 1.4 percent of Huawei shares, allowing him and his executive team to maintain strategic control of Huawei (Feng and Li 2020).

Huawei and ZTE were among a number of domestic companies that developed digital telecom switch technology indigenously. But their eventual successes benefited from earlier state investment in developing indigenous technologies. The state-owned Datang Telecom Group, with direct support from the government, had failed to master through reverse engineering the program-controlled switching technology packaged in specialized semiconductor chips. An unexpected success occurred in 1991, however, when a small state-owned firm, Julong, introduced an innovative, indigenously developed public switching system (PDSS) model, the HJD-04 switch. Julong succeeded where Datang failed because it drew on the experience of its scientists and engineers who were involved in developing mainframe computers for the military. The similarity between computer and PDSS technologies enabled Julong's engineers to understand the core technology of digital switching embedded in chips and recreate it with simpler components and designs.

Inspired by the HJD-04, Huawei and ZTE followed a strategy to develop indigenous switches through system integration. By 1993, both Huawei and ZTE launched their first digital telecom switch models, C&C08 and ZXJ10, respectively. These digital switches had decent quality and sold at much lower prices than the imported technologies. To compensate for inferior technology initially, Huawei had sent out armies of engineers to operators' sites, most of them in remote or rural areas, to solve software bugs and make adjustments for local conditions. The knowledge and experience accumulated from learning from customers subsequently become an important part of Huawei's innovative capability (Li 2022, ch. 3).

Throughout the 1990s, Huawei and ZTE made commitments to technological learning, with both companies reinvesting around ten percent of revenues in R&D activities (Fan 2006; Fan and Gao 2016; Li 2017). Both companies made numerous organizational arrangements for joint product development with state labs, universities, and JV companies. To rapidly expand their engineering base, both companies aggressively recruited talent from the state sector, especially targeting seasoned engineers trained by JVs. In the late 1990s, for example, Qingdao-Lucent lost half of its testing engineers to Huawei, while large numbers of engineers trained at Shanghai-Bell moved to Huawei and ZTE.

Using a combined strategy of lower-cost, higher-quality technology and excellent customer service, Huawei and ZTE seized the less-profitable but massive Chinese rural market by the end of the 1990s. From there, they quickly made inroads into international markets by exporting switches to developing economies in Asia, Africa, and Latin America. By the early 2000s, Huawei and ZTE had succeeded in the wireless telecom-equipment business at home and abroad to become substantial multinational enterprises.

By the end of the 2010s, Huawei would become the world leader in communication infrastructure with, in addition, leading positions in smartphone technology and enterprise networking. In 2020, Huawei held 31 percent of the global communication-infrastructure market and ZTE 10 percent, with Sweden's Ericsson and Finland's Nokia each at 15 percent (Waring 2021). There is evidence that by not exposing itself to the stock market Huawei has been able to retain profits and people to invest in innovative productive capabilities (see Carpenter and Lazonick 2017, 2022).

The experiences of Huawei and ZTE show that their successful innovation strategies included investing heavily in emerging technologies, luring away with better compensation trained managers and engineers from the state-owned sectors, and making superior use than SOEs and JVs of this talent. Supporting these aggressive investment strategies was a massive and fast-growing domestic market, with Huawei and ZTE initially developing their productive capabilities by supplying equipment to the underserved rural markets in China. With the ambition to become industry leaders, Huawei and ZTE allocated profits to build superior organizational capabilities and engage in the indigenous-innovation process of absorbing and improving on technologies that had emanated from the Chinese state sector, interactions with foreign multinational enterprises, or the return from abroad of knowledgeable and experienced Chinese personnel.

Within a nation, indigenous innovation in one market segment can provide organizational and technological foundations for the growth of the innovative enterprise in related market segments. Huawei has been able to build on its leadership in producing telecommunication equipment for service providers to attain significant market share in enterprise networking equipment, in which the global leader has been Cisco, with 41 percent of the world market in 2020, down from 44 percent in 2019 (Boujelbene 2021). Huawei was a distant, but steadily rising, second, with nine percent in 2019 and ten percent in 2020, followed by HPE Aruba with five percent in each year and Palo Alto Networks with four percent.

Of even more importance, in May 2019, Huawei surpassed Apple to become the world's second-largest smartphone producer (Eadicicco 2019) and in April 2020 had briefly overtaken Samsung to become the world leader (Doffman 2020). But Huawei's wholly owned chip-design company, Hi-Silicon, relied on the Taiwan Semiconductor Manufacturing Company (TSMC), the pioneer in the "pure play" foundry model of semiconductor fabrication, for the processors for its advanced smartphones. Coming into the fourth quarter of 2020, Hi-Silicon was TSMC's second-largest customer, after Apple. In 2019, Apple had accounted for 24 percent of TSMC's revenues and Hi-Silicon 15 percent, and in the third quarter of 2020 TSMC began shipping smartphone chips to the Chinese company produced on the fabricator's 5nm technology (Friedman 2020; Lazonick and Hopkins 2021).

In May 2020, as a key part of the Trump administration's trade war with China, the US government began to coerce TSMC to cease selling chips to Huawei (Shepardson et al, 2020; Friedman 2020). In the third quarter of 2020, 59 percent of TSMC's revenues came from North America, followed by 22 percent from China (TSMC 2020). In the fourth quarter of 2020, revenues from North America soared to 73 percent of TSMC's total, while those from China plummeted to six percent (TSMC 2021), as TSMC complied with US government directives to cut off Huawei's chip supply completely.

The result of this US trade policy, which has been maintained by the Biden administration, has been a dramatic decline in Huawei's smartphone sales. By the second quarter of 2021, Huawei was not even among the top five smartphones sold in China, although its Honor brand, which Huawei had spun off as an independent company to avoid US sanctions, held fifth place (Yordan 2021; Bloomberg News 2021). With no chips going to Huawei from the fourth quarter of 2020, TSMC abruptly lost its second largest customer (Lazonick and Hopkins 2021).

Yet from 3Q20 to 4Q20 TSMC's smartphone revenues increased from 46 percent to 51 percent of total sales and its profits rose by 4.0 percent. At the same time, 5nm wafer revenue, predominantly from the fabrication of the most advanced smartphone processors, which had been zero percent of TSMC's total in 2Q20 and eight percent in 3Q20, jumped to 20 percent in 4Q20. In supporting TSMC's revenues and profits by increasing its purchase of 5nm chips, Apple in effect partnered with the US government to demolish the smartphone business of Huawei, its prime global competitor (Lazonick and Hopkins 2021).[12] This case shows the strategic importance for China's development path of engaging in indigenous innovation in all technology sectors, none of which are more critical than semiconductor fabrication.

4.4. Semiconductor fabrication: Business-government collaboration in a critical industry

In 2006, China officially announced its "indigenous innovation" policy, with the goal of breaking away from the reliance on foreign technology under the TMFT paradigm. Over the next decade, China promoted the development of advanced industries through the Strategic Emerging Industries (2010), Made in China 2025 (2015) and Self-Reliance in S&T (2020) policy agendas. Central to the Chinese indigenous innovation policy is the semiconductor

[12] On semiconductors and the Trump trade war with China, see also Brown (2020), who, however, erroneously views the purpose of US government policy of halting semiconductor sales to Huawei as the Chinese company's radio base stations. In fact, the target was Huawei's smartphone business.

industry, a crown jewel of the information-technology industries and a market segment in which China relies heavily on foreign technology and imports. In the creation of a modern semiconductor industry in China, the inflows of returnees (海归 or literally "sea turtles") with advanced training from abroad played an important role in filling the skill gaps in senior management and technology positions (Saxenian 2005; Zhou 2008b). Drawing on Li (2011, 2016, 2017, 2022), we consider the case of the semiconductor industry as an example of indigenous innovation in the 2000s and 2010s.

China's history of building a domestic semiconductor industry goes back to the 1960s (Simon 1987), but it was only after the 1978 economic reforms that the Chinese government made a concerted effort to upgrade the state-owned semiconductor industry through importing advanced machinery and establishing Sino-foreign JVs. The first of two notable initiatives in the 1990s was the State Project 908, launched in 1990, in which the government invested RMB2 billion to import 6-inch wafer fabrication lines from AT&T Technologies, which became Lucent Technologies in 1996, to upgrade a major SOE, Huajing Microelectronics. The project was severely delayed due to a lack of funding, and later Huajing did not have the expertise to run the expensive fabrication line profitably. In 1998, Huajing leased the line to CSMC, a Hong Kong-based company, which recruited ethnic Chinese engineers and managers from the United States and Taiwan. The returnee managers turned Huajing's fab into a profitable operation in just a year. Although Project 908 did not achieve its official goal, the demonstrated ability of returnee managers at Huajing/CSMC encouraged the Chinese government to focus on attracting more overseas talent for the semiconductor industry in the 2000s.

The other major initiative was Project 909 in 1997, a joint venture between the Chinese government and Japan's NEC to import 8-inch wafer fabrication lines. Huahong-NEC, the JV semiconductor firm, had a head start by rapidly constructing facilities and ramping up production. In 1999, Huahong-NEC became profitable in its first year of operation. But Huahong-NEC was not much more than an NEC subsidiary, relying heavily on Japanese technology and management expertise. Huahong-NEC suffered heavy losses from the downturn following the 2000 dotcom bust, and with the decline of NEC's semiconductor division, Huahong-NEC eventually sought returnee managers in the 2000s. Nevertheless, Project 909 had its legacies as well: Chinese cities, especially Shanghai, had invested in infrastructure and a skilled labor force for this advanced industry, and with this experience, they invested heavily in the semiconductor industry within their jurisdictions over the next two decades (see Li 2016).

A significant change in the national strategy to promote the semiconductor industry occurred when the State Council issued "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, in 2000. The new policy removed de facto barriers for foreign and domestic entry, providing incentives to semiconductor firms regardless of ownership. Following Circular 18, Chinese expatriates returned from the global semiconductor industry centers of the United States, Taiwan, and Singapore to establish a burgeoning industry. In the fabless sector, the number of semiconductor design houses increased from less than 100 in 2000 to over 500 in the mid-2000s (PwC 2010). In the foundry sector, in 2000, teams of returnee managers and engineers founded two large-scale manufacturing firms, Semiconductor Manufacturing International Corporation (SMIC) and Grace Semiconductor in Shanghai's Pudong New Area development zone.

In contrast to the state-backed projects in the previous decade that had built vertically integrated IDMs (integrated device manufacturers), SMIC and Grace introduced the pure-play foundry operation model pioneered by TSMC. Initially, the pure-play model allowed SMIC and Grace to grow by manufacturing chips for leading multinational semiconductor firms as part of their global value chains. Over time, these advanced manufacturing capabilities have increasingly served local design houses and underpinned the expansion of a Chinese semiconductor ecosystem.

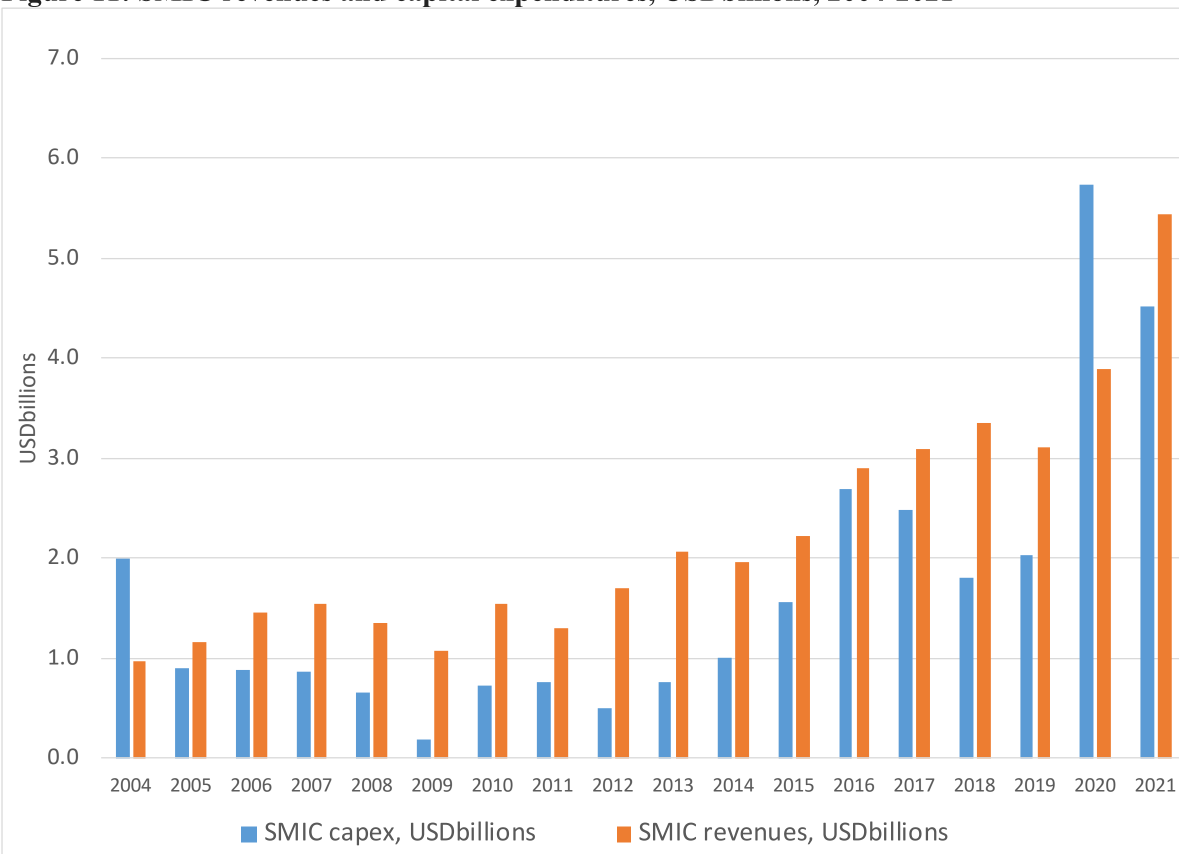
SMIC is a model of returnee entrepreneurship. Accounting for more than half of China's production capacity, SMIC is the largest and most sophisticated Chinese foundry. It was launched in 2000 by Dr. Richard Chang, a 20-year veteran at Texas Instruments, who organized a team of over 300 ethnic Chinese and 100 returnee managers and engineers in Shanghai. Backed by Chinese and international investors as well as subsidies from the city government of Shanghai, SMIC executed an aggressive expansion strategy combining greenfield projects and acquisitions (e.g., Motorola's Tianjin fabs) to meet existing demand, rapidly achieving economies of scale. By 2004, SMIC already owned four 8-inch and one 12-inch fabrication lines, making it the world's third largest pure-play semiconductor foundry by revenue.

Innovation in the semiconductor industry requires continuous investment in advanced technology, production facilities, and a skilled labor force on a large scale and over a sustained period of time (Kim 1997; Matthews and Cho 2000). The difficulty that SMIC confronted to maintain a high investment rate from 2005 to 2014 illustrates the obstacles to engaging in indigenous innovation. As it sought to integrate a diverse workforce of local, returnee, and foreign employees, SMIC faced intellectual-property lawsuits brought by TSMC that forced the departure of the founder Chang in 2009. While SMIC struggled to maintain a self-sustaining business, its sources of funding, including bank loans, stock-market issues, and subsidies from local governments, could not meet its needs for financial commitment. In the early 2010s, SMIC substantially reduced capital expenditures to remain profitable, but as a result the firm's lag behind global technology leaders widened from one to two generations in the early 2000s to nearly four generations in 2014 (Li 2022, ch. 5).

In 2014, the Chinese government established the National Integrated Circuit Industry Investment Fund—also known as the "Big Fund", as opposed to "smaller" IC industry funds of local governments—to invest in key semiconductor companies. The Big Fund eventually provided the financial commitment that SMIC needed to invest in the state-of-art fabrication lines. From 2015 to 2018, SMIC and its subsidiaries received RMB21 billion equity investment from the Big Fund, making it the largest recipient, followed by Yangtze Memory Technology Co. Ltd. (RMB19 billion) in the Fund's RMB105-billion budget. That investment finally enabled SMIC to move to the advanced 14nm FinFET process technology that only American, Korean, and Taiwanese companies had mastered so far.

Figure 11 shows SMIC revenues and capital expenditures in USD billions for 2004 through 2021. Note the elevated capex levels in 2015-2019, when Big Fund equity investments became available. Then, in response to the US-China trade war, SMIC capex soared from an average of USD2.1 billion in 2015-2019 to USD5.7 billion in 2020 and USD4.5 billion in 2021. These increases in spending on plant and equipment were accompanied by substantial increases in revenues, reaching $5.4 billion in 2021. Yet, there remain significant technological and financial obstacles for SMIC to develop the leading-edge sub-10nm technology to join the league of industry leaders, TSMC and Samsung (Lazonick and Hopkins 2021).

Figure 11: SMIC revenues and capital expenditures, USDbillions, 2004-2021



Sources: Semiconductor Manufacturing International Corporation, annual reports and quarterly presentations

The returnee-entrepreneurship model of SMIC has been widely adopted in segments of the semiconductor industry. In the fabless design sector, Spreadtrum Communications, founded by a group of Chinese engineers in Silicon Valley in 2001 and acquired by Tsinghua Unigroup in 2013, became one of the largest smartphone chipset suppliers in the world. In the semiconductor equipment segment, Dr. Zhixiao Yin, previously a vice president of Applied Materials, founded Advanced Micro-Fabrication Equipment Inc. (AMEC) in Shanghai in 2004, which now sells some of the most advanced plasma etching equipment to leading foundries. In the memory chip segment, Yangtze Memory Technology Co. Ltd., originated from a local-government-financed, SMIC-managed foundry in Wuhan to become China's most advanced NAND flash memory maker after appointing Dr. Shining Yang, previously a senior R&D engineer at Intel and COO of SMIC (2010-2013), as its CEO in 2013. Spreadtrum, AMEC, and Yangtze Memory have all received substantial investments from the Big Fund.

The returnee entrepreneurship model extends to advanced industries beyond semiconductors. For example, in China's booming photovoltaic industry in the 2000s, the leading firm Suntech was founded by Dr. Zhenrong Shi, a returnee scientist from Australia, with funding from the city of Wuxi.[13] The Shenzhen-based world leader in civilian drones, DJI, was founded by Tao Wang when he was a graduate student in engineering at Hong Kong University of Science and Technology in 2006, with a small research grant of HKD18,000 from HKUST to develop prototypes.

While devolving control over strategic decision-making to returnee entrepreneurs and managers, the Chinese government has remained ready to provide committed finance to the innovation process when high-fixed-cost non-governmental enterprises have lacked access to sufficient funds from other sources. It may take another decade or so to see the results of these Chinese government-business collaborations in semiconductor fabrication. Success or failure will depend on the interaction of strategic control, organizational integration, and financial commitment as social conditions of innovative enterprise.

As returnees brought managerial and technology expertise to China, they brought home elements of a "New Economy" business model (see Lazonick 2009b) from the United States as well. In business strategy, Chinese semiconductor firms follow their American counterparts in vertical specialization and deep embeddedness in the global value chain, rather than the vertical integration model of older Japanese, Korean, or US firms. The reliance on returnee expertise is a stage of technological learning in many of China's advanced technology industries. As successful entrepreneurial firms transform into going concerns and home-grown capabilities develop, Chinese companies inevitably must build on learning from abroad to move to the phase of indigenous innovation when developing superior processes and products. A few Chinese companies, such as Huawei in communication technology, DJI in civilian drones, and BAT (Byte Dance, Alibaba, and Tencent) in Internet services may have arrived at that stage. However, given the size and breadth of China's industrial economy, the development paths to indigenous innovation that we have charted will continue to unfold in many industrial sectors in years to come.

5. China's Path and Global Competition

In this essay, we have provided a framework for analyzing the role of industrial innovation in the development of the Chinese economy. We have illustrated how government investments in human capabilities and physical infrastructure have combined with business investment in technology learning to create the foundations for indigenous innovation in key industries. From a theoretical perspective, our analysis of China's development path demonstrates the

[13] See Hopkins and Li (2016) for a detailed discussions of 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. strategic control and financial commitment in the performance of the US industry

importance of the combination of investment in productive capabilities by the developmental state and the innovative enterprise in the growth of a major national economy.

The case of China highlights the role of a developmental state in investing in an array of productive resources available to the business sector. Some of these resources in the realms of education, the S&T system, and infrastructure are public goods and services that the state has provided in any national economy that has achieved sustained economic growth. The Chinese state has not, however, been a passive investor in these productive resources. It has implemented proactive policies to support the expansion of advanced manufacturing capacity by attracting, negotiating, and coordinating foreign investment, and by fostering the inflows of talent and knowledge to China. Such investments have formed the foundation of the nation's technological learning. Furthermore, to foster innovative business enterprises, the Chinese government often has provided sustained funding, often described as "patient capital", which otherwise would not have been available through nonstate financial channels.

The case of China also demonstrates that the success of the developmental state in fostering a dynamic of growth eventually depends on the emergence of innovative enterprises. From the perspective of the theory of innovative enterprise, the importance of *indigenous* innovation derives from the concept of the locus of strategic control. Companies that seek to become global competitors in technology industries must go beyond technology learning from abroad to develop superior productive capabilities at home. Key to indigenous innovation are, first, the devolution of strategic control to autonomous business enterprises that can engage in domestic and global competition by investing in learning processes, and, second, the exercise of strategic control within these business enterprises by senior executives who have both the abilities and incentives to allocate corporate resources to investment in innovation.

As indicated in this essay, a distinctive feature of China's development path has been the wide range of governance structures, from *minying* to employee ownership to joint ventures to state-owned enterprises to venture-backed startups, under which innovative firms have emerged since the 1980s. The key issue is not the form of enterprise ownership but rather the abilities and incentives of those who exercise strategic control, given an ownership structure. Not all Chinese firms possess these strategic capabilities, but, from our study of China's development path, it is our contention that the most successful Chinese companies have been those in which, given the supportive national ecosystem, senior executives have had the autonomy, ability, and incentive to invest in innovation.

Strategic control over corporate resource allocation gives top executives the power to invest in the productive capabilities of the workforce and, through organizational integration, transform those productive capabilities into the organizational-learning processes that are the essence of innovation, enabling the generation of higher-quality, lower-cost products.[14] Building these organizational capabilities inevitably entails the high fixed cost of attracting, training, motivating, and retaining the labor force engaged in organizational learning. For innovation to be successful, this fixed-cost investment in productive capabilities must result

[14] At this level of analysis, our perspective has much in common with the focus on David Teece and colleagues on "dynamic capabilities" (see Teece 2009). For ways in which our "social conditions of innovative enterprise" perspective differs from a version of the "dynamic capabilities" perspective, see Lazonick (2018).

in a higher-quality product than would otherwise have been available for the firm's targeted market segment. Then, by virtue of possessing a higher-quality product, the innovating firm can transform the high fixed cost of developing that higher-quality product into low unit cost by accessing a large extent of that market segment, thus achieving economies of scale. Over the last four decades, those Chinese companies which have been able to generate higher-quality products have had the advantage of access to both a rapidly growing domestic market, resulting from national economic growth, and a massive export market enabled by China's participation in the global economy.

In addition to strategic control and organizational integration, innovative enterprise requires financial commitment. To accumulate technological capability, Chinese companies have reinvested profits in productive capabilities, often complemented by loans from the state-run banking system. This financial commitment has combined with strategic control and organizational integration as social conditions of innovative enterprise for Chinese firms (Lazonick 2010b, 2015, 2019). Underpinning the success of enterprise growth in China has been the dynamic interaction of innovative business strategy and developmental government policy.

As principles of economic transformation, the social conditions of innovative enterprise that have enabled China's development path are not unique to China. In the 1980s, following the publication of Chalmers Johnson (1982), *MITI and the Japanese Miracle*, it became common to credit the "developmental state" for Japan's rise to global leadership in a range of mass-production industries. Yet, from the late nineteenth century, it was the United States that possessed the most formidable developmental state in history (Hopkins and Lazonick 2014). From the perspective of the accumulation of knowledge that provided a foundation for Japan's indigenous innovation, the United States, first and foremost among the advanced economies, functioned as Japan's developmental state (Lazonick 2010a). Central to Japan's success was the growth of innovative enterprises, supported by national institutions—specifically, stable shareholding, permanent employment, and main-bank lending—that provided Japanese corporations with the social conditions that enabled indigenous innovation and, in many cases, subsequent transition to global technology leadership (Lazonick 2005).[15]

By transferring this knowledge from abroad and then improving upon it, by the last decades of the century Japanese corporations were outcompeting their US rivals in industries such as automobiles, consumer electronics, machine tools, and steel, in which US companies had been world leaders. The organizational foundation of US leadership in mass-production industries had been the combination of secure employment under the norm of a career with one company for both blue-collar operatives, typically organized in unions with first-hired, last-fired seniority provisions, and white-collar engineers, whose attachment to the company was cemented by promotion up the corporate hierarchy and the availability of company-funded nonportable defined-benefit pensions, based on years of service with the company. These employment relations characterized what Lazonick has called the "Old Economy business model" (OEBM) (Lazonick 2009a; 2010a).

[15] For the adaptation of Japanese corporations to the transformed global economy of the last three decades, including the emergence of China as a major competitor, see Schaede (2008; 2020).

Under Japan's system of permanent (aka "lifetime") employment, which evolved in the post-World War II decades, blue-collar operatives and white-collar engineers also had, as in the United States, employment security over the course of their careers. In the United States, however, there was an organizational segmentation of the routine work of "semi-skilled" operatives from the organizational learning among engineers who were deemed to be part of the management structure (Lazonick 2007; 2010a). In sharp contrast, the key source of Japanese competitive advantage in the mass-production industries was organizational integration of the skills and efforts of shop-floor operatives with those of professional engineers to enable the collective and cumulative learning required to generate higher-quality, lower-cost products (Lazonick 1998; 2007; 2010a). In effect, the Japanese surpassed the United States in mass-production manufacturing by perfecting the OEBM.

In the 1970s and 1980s, as an outcome of indigenous innovation commenced in Japan in the 1950s, Japanese electronics corporations also used their integrated skill bases to become global leaders in memory chips, a segment of the semiconductor industry in which value is added by reducing defects and increasing yields. This development forced major US semiconductor companies to retreat from this segment of the market, with Intel facing the possibility of bankruptcy in the process (Burgelman 1994; Okimoto and Nishi 1994). Led by Intel with its microprocessor for the IBM PC and its clones, US companies became world leaders in logic chips, in which value is added through design and functionality. Indeed, the IBM PC, with its open-systems "Wintel" architecture, formed the basis for the rise of a "New Economy business model" (NEBM), characterized by offshoring and outsourcing of manufacturing, mainly to Asia; insecure employment, marked by interfirm labor mobility, stock-based pay, and portable defined-contribution pensions; and the rise of a global technology labor force, with India and China playing leading roles in the supply of highly educated people, particularly to the tech industry of the United States (Lazonick 2009a; Lazonick et al. 2014; Lazonick et al. 2022).

With ten times the population of Japan and the world's second largest economy, China has emerged as a powerful global competitor, engaging in indigenous innovation through its global participation in the US-led NEBM (Lu 2000; Feng 2020; Li 2022). Despite their accumulated technological capabilities in information and communication technology, Japanese firms failed to emerge as major global competitors in the mobility revolution because they remained ensconced in the OEBM (Kushida 2011; Carpenter and Lazonick 2017). In contrast, China's emergence as a global competitor in ICT, with companies such as Lenovo, Huawei, and Alibaba, has been based on taking a development path that has become integral to NEBM on a global scale, with a pervasive presence in global value chains (Milberg and Winkler 2013; Sun and Grimes 2018; Li 2022).

As, through the process of indigenous innovation, Chinese companies have emerged as major global competitors, many US technology companies have fallen victim to corporate financialization (Lazonick 2022). The starkest contrast is between the success of Huawei Technologies in communication infrastructure, in which the company is the world leader (followed by Sweden's Ericsson and Finland's Nokia), and the failure of US-based Cisco Systems to become a significant competitor in this segment. In a forthcoming paper, "The Pursuit of Shareholder Value: Cisco's Transformation from Innovation to Financialization," Marie Carpenter and William Lazonick document how, at the turn of this century, Cisco was positioned technologically to build on its global leadership in enterprise-networking equipment to become a major competitor in the more sophisticated service-provider infrastructure segment. To do so, Cisco would have had to make large-scale investments in manufacturing and marketing as well as R&D. Instead, from 2002-2021, Cisco distributed USD144 billion (98 percent of net income) to shareholders in the form of stock buybacks as well as USD48 billion (another 33 percent of net income) as dividends (Carpenter and Lazonick 2022). More generally, corporate financialization has robbed the United States of the possibility of attaining a leadership position in 5G and IoT.

As indicated earlier, in smartphone competition with Huawei, Apple has benefited immensely from US trade policy that, from the fourth quarter of 2020, eviscerated the Chinese company's high-end smartphone output by coercing TSMC to stop shipping advanced nanometer chips to HiSilicon, Huawei's chip-design subsidiary. Yet TSMC's rise to global dominance of advanced chip fabrication was enabled by the fact that Apple itself chose to outsource semiconductor fabrication while, between October 2012 and June 2022, wasting USD529 billion on stock buybacks (96 percent of net income) to give manipulative boosts to its stock price. Apple could have deployed just a fraction of this cash to fund on a sustained basis its own state-of-the-art fab—as indeed an industrial journalist suggested to Apple CEO Steve Jobs in 2010 (LaPedus 2010). To put the magnitude of this corporate financialization in perspective, the combined USD27 billion that TSMC and Samsung Electronics committed to spending over several years from 2021 to launch state-of-the-art fabs in the United States was less than one-third of the USD86 billion that Apple spent on buybacks in 2021 alone (Lazonick and Hopkins 2021).

Meanwhile, as has explicitly been recognized by Pat Gelsinger, Intel's CEO, who took office in February 2021, corporate financialization has been a prime cause of that company's loss of world leadership in chip fabrication to TSMC and Samsung (Lazonick 2022). China's SMIC may be struggling to catch up with the Taiwanese and Korean companies in advanced nanometer platforms, but Intel's financialization has helped create an opening for SMIC's development path. The same argument can be made about how Boeing's corporate financialization, manifested by USD43 billion in buybacks from January 2013 to the first week of March 2019, just before the second of the two Boeing 737 MAX crashes (Lazonick and Sakinç 2019), crippled a US-based technology leader, enhancing the possibility that China's Comac, with its C919 (Pfeffer and Riordan 2021), might break into the Boeing-Airbus duopoly in the global manufacture of large aircraft.

More generally, a book could be written about how US-based companies have supported China's development path to the mutual benefit of both nations, but how the US-based companies have squandered these gains in the name of "maximizing shareholder value" (see Lazonick 2013; Lazonick and Shin 2020). Indeed, such a book could focus solely on the story of China's rise to global leadership in green technology, with corporate financialization causing the United States to fall further and further behind (see, e.g., Hopkins and Li 2016; Lewis 2016; Ambrose 2021; Cohen 2022). For the past decade or so, as the success of China's development path has become clear in global competition, US interests have complained about China's currency manipulation, intellectual property theft, unfair government subsidies, violation of WTO rules, and attacks on US national security. While, depending on the facts of the matter, there may be cause for US concern on any or all of these issues of US-China relations, a policy agenda that limits itself to litigating these questions will fail to comprehend the technological learning that since the 1980s has been driving China's development path. At the same time, this US penchant for blaming China will ignore, or at best underestimate, the damage to the development path of the United States that corporate financialization has wrought.

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