



Chinese Semiconductor Industrial Policy: Prospects for Future Success

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Abstract

This paper, the second in a two-part series analyzing the Chinese semiconductor industry, attempts to answer two questions: First, why—in spite of 70 years of industrial planning efforts—can't China make advanced semiconductors on par with the worldwide industry leaders? Second, what are China's prospects for success with its current semiconductor industrial plans? This paper reviews the development of the semiconductor industries in Taiwan, Japan, and South Korea in the context of literature on latecomer strategies and compares their development with China's efforts. The paper also considers China's prospects for success. China's current plans are well defined, with national champions focusing their efforts on targeted subsectors of the industry, but these efforts will not achieve their desired success due to a lack of human capital and intense international competition.

Keywords: Semiconductors, China, trade, latecomer strategies, integrated circuits, global value chains, industrial planning, export controls.

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Introduction¹

The worldwide semiconductor industry² is concentrated in only a few geographical areas, with industry leaders located in Europe, Taiwan, Japan, the United States, South Korea, and China. In addition to its geographic concentration, the number of firms engaged in the industry has consolidated over time. At the same time, the focus of many of these firms has narrowed. Only a handful of companies such as Intel and Samsung can produce an advanced chip from start to finish, making them “integrated device manufacturers,” or IDMs. Over the past 30 years, in an effort to save costs, a number of firms have started to specialize in one or more stages in the production process.

Production occurs in three general stages: design; manufacturing; and assembly, test, and packaging (ATP). Some companies like Qualcomm and AMD engage solely in semiconductor design work and are known as “fabless” firms in industry jargon. Other companies, known as “pure play” foundries, focus exclusively on contract chip manufacturing (in factories known as “fabs”), taking the designs of fabless firms and fabricating chips. After fabrication, these nearly complete chips can be sent to a third firm that focuses on ATP before the chips are ready to be incorporated into a final good, such as a smartphone.³

China currently aspires to develop a closed-loop semiconductor ecosystem, where Chinese-headquartered firms design, manufacture, and carry out ATP on chips for domestic consumption.⁴ As detailed in Part I of this series, the semiconductor industry has been the subject of Chinese industrial plans since the 1950s. China considers semiconductor industry development a strategic priority, given the economic and national security benefits of having a commercially viable supply of domestic chips. In addition to the economic benefits derived from increasing domestic production and relying less on imports, the Chinese government believes that depending on foreign production of semiconductors is a significant national security vulnerability and seeks a reliable domestic supply.

China has designed three industrial policies in pursuit of this goal: Guidelines to Promote a National Integrated Circuit Industry (National IC guidelines), Made in China 2025, and the Made in China 2025 Technical Area Roadmap. Released in 2014 and 2015, these plans leverage

¹ For a discussion of the current structure of the worldwide semiconductor market, China’s evolving role in the semiconductor global value chain, and China’s past and present semiconductor industrial plans, see Part I of this series: VerWey, *Chinese Semiconductor Industrial Policy: Past and Present*, July 2019.

² A semiconductor is a material that has electrical conductivity between that of conductors (e.g., copper) and insulators (e.g., glass). There are three types of semiconductors: discretely, optoelectronics/sensors, and integrated circuits (ICs). Discretely are semiconductors that only contain one transistor. Optoelectronics are semiconductors that detect or generate light. ICs are semiconductors that contain more than one transistor. The colloquial term “chips” can refer to any type of semiconductor.

³ See SIA, *Beyond Borders*, 2016, for a thorough illustration of this global value chain.

⁴ USTR, *Section 301 Report*, 2018, 113.

subsidies (investment funds and tax breaks) and zero-sum tactics (investment restrictions and technology transfer requirements) to accelerate the domestic industry's development.

The National IC Guidelines, Made in China 2025, and the Technical Area Roadmap are only the most recent iterations in China's ongoing efforts to develop a commercially viable domestic semiconductor industry. This raises an obvious question: why have all the previous attempts failed? While there has been some analysis of China's past failed attempts in both the popular press and academic literature,⁵ this question is particularly timely given the size and scale of China's current plans. This paper finds that China's efforts to develop its semiconductor industry have been hampered by an inability to strategically and efficiently allocate funds as well as a lack of human capital.

The remainder of this paper is divided into three sections. First, the paper describes the experiences of Japan, South Korea, and Taiwan in brief, focusing on their respective semiconductor industry success stories and the limits of their success. The paper then discusses industry-specific challenges that China faces. The final section assesses prospects for success with China's current industrial plans, before concluding with a discussion of the China-specific challenges that remain.

East Asian Semiconductor Industry Latecomers

Japan, South Korea, and Taiwan were not among the first countries to build a semiconductor industry. However, despite considerable technical challenges and barriers to entry, these three countries all developed commercially viable companies in this sector in the past 30 years.⁶ Using a combination of government support, specialization, advantageous timing, and innovation, each country's industry has emerged as competitive in one or more market segments, from foundry services to memory chips.

There is a large body of academic literature that analyzes so-called "latecomers" to a particular industry, identifying advantages that make it easier for these firms to mitigate inherent first mover advantages and high barriers to entry.⁷ Among the latecomer advantages identified are the ability to leverage already-developed supply chains, free-rider effects (no need to invest large sums in basic research and development), better information (about market size, trends, and dynamics), and a pre-developed pool of human capital to draw upon. Late-industrializing industries also benefit from large-scale state support, frequently in the form of subsidies, which distort prices to stimulate economic growth.⁸ These tactics and advantages are addressed in profiles of each country's semiconductor industry development below.

⁵ Minter, "Why Can't China Make Semiconductors?" April 29, 2018; Fuller, "Limited Catch-Up in China's Semiconductor Industry," 2019.

⁶ For a definitive history of the development of East Asia's semiconductor industry see Mathews and Cho, *Tiger Technology*, 2000.

⁷ Cho, Kim, and Rhee, "Latecomer Strategies," 1998.

⁸ Amsden, *Asia's Next Giant*, 1989, 10.

Development of the Japanese Semiconductor Industry

The development of Japan's semiconductor industry began in the 1960s and was bolstered by focused investments, fortuitous timing, an emphasis on productivity rather than innovation, and government support. Throughout the 1960s and 1970s, Japanese firms engaged in license agreements with U.S. firms that resulted in a substantial amount of technology transfer, all while those U.S. firms were prevented from directly investing in Japan.⁹ Using this expertise, Japanese firms targeted the emerging dynamic random-access memory (DRAM) market. These firms succeeded in reducing U.S. market share from 70 to 20 percent between 1978 and 1986, while the Japanese share increased from less than 30 percent to nearly 75 percent.¹⁰

This success was driven by Japanese firms' investments in process innovation and manufacturing quality at a time when the U.S. industry was focused on product innovation.¹¹ It was also reinforced by well-defined end-use cases, given that many of organizations that entered the semiconductor business were telecommunications firms (e.g., NEC, Fujitsu), industrial conglomerates (e.g., Hitachi, Toshiba), and consumer electronic companies (e.g., Sharp). This allowed Japanese chipmakers to focus on narrow-use cases in response to internal company demand that provided a test market for a given chip, enabling fast feedback loops.¹² Japanese firms' strategic targeting of DRAM was bolstered by government-sponsored cooperative research, which allowed firms to share in knowledge spillovers.¹³ Initial studies of Japanese firms' success ascribed their rapid progress to these policies and more general industrial policies pursued by the Ministry of International Trade and Industry (MITI), though later analysis points to the close relationship between Japanese semiconductor firms and Japanese banks. Japanese banks allowed Japanese semiconductor firms to weather the industry's downturns via countercyclical injections of capital.¹⁴

The success of Japanese semiconductor firms raised alarms among the U.S. industry. A 1983 report from the Semiconductor Industry Association described Japan's production of DRAM as a "bellwether for the industry" insofar as success in that particular fabrication process allowed firms to reduce costs and enhance production in other product lines.¹⁵ In 1986, the U.S. industry successfully lobbied the U.S. government to impose antidumping protections and a guarantee of 20 percent market share in the Japanese market within five years, though the efficacy of these actions remains subject to debate.¹⁶

⁹ Irwin and Klenow, "Learning-by-Doing Spillovers," 1994, 1206.

¹⁰ Irwin, "US-Japan Semiconductor Conflict," 1996, 7.

¹¹ Langolis and Steinmueller, "Strategy and Circumstance," 2000, 1167.

¹² Cho et al, "Latecomer Strategies," 1998, 493-496.

¹³ Irwin and Klenow, "Learning-by-Doing Spillovers," 1994, 1205.

¹⁴ Irwin, "Trade Politics and the Semiconductor Industry," 1996, 25.

¹⁵ SIA, "The Effect of Government Targeting," 1983, 59.

¹⁶ Irwin, "Trade Politics and the Semiconductor Industry," 1996, 12.

Development of the Taiwanese Semiconductor Industry

The development of the Taiwanese semiconductor industry featured a combination of government support, specialization, and innovation. The industry began with the establishment by General Instrument (U.S.) of an integrated circuit (IC) assembly facility in a Taiwanese export-processing zone in 1964.¹⁷ The Taiwanese government's support for this nascent semiconductor industry accelerated with its 1973 decision to establish the Industrial Technology Research Institute (ITRI), a public research and development body. ITRI and the HsinChu Science Park, a high-tech zone developed with tax subsidies, facilitated acquisition of key semiconductor technologies, some of which were ultimately spun off into independent companies. Notably, United Microelectronics Corporation (UMC) was a product of ITRI; beginning operations in 1980, UMC has grown to be the second-largest foundry by production volume in the world today.¹⁸ These efforts were bolstered by the return of 19,000 U.S.-trained Taiwanese technicians between 1980 and 1988.¹⁹

The most prominent example of a Taiwanese returnee in the semiconductor industry is Morris Chang, a former Texas Instruments executive who was recruited to lead ITRI in the 1980s. He left his post at ITRI in 1987 to found Taiwan Semiconductor Manufacturing Company (TSMC), pioneering an entirely new operating model in the semiconductor industry known as the “pure play” foundry. As discussed above, as well as in Part 1 of this series, a pure-play foundry focuses exclusively on semiconductor device fabrication, leaving chip design and ATP to other firms. This operating model allows foundries to invest profits in increasing the sophistication of their production process, unlike IDMs, which must split their budgets between product innovation and fabrication process innovation.²⁰ TSMC has since grown to be the largest and most advanced semiconductor foundry in the world by production volume.²¹

The combination of government support, skilled workers, and the creation of a new operating model that came to dominate a subset of the industry also facilitated Taiwan's success in IC design, which led to a complete semiconductor manufacturing ecosystem in Taiwan.²² Between 1985 and 1988, the number of firms engaged in IC design in Taiwan grew from 8 to 50; by 1999, 91 percent of their fabrication work needs were met by local foundries, while 99 percent of semiconductor packaging demand was met by local supply.²³

Development of the South Korean Semiconductor Industry

The development of the South Korean semiconductor industry synthesizes aspects of the Japanese and Taiwanese models. Large multinational corporations (MNCs) established semiconductor

¹⁷ Amsden and Chu, *Beyond Late Development*, 2003, 40.

¹⁸ Amsden and Chu, *Beyond Late Development*, 2003, 107.

¹⁹ Chen and Jan, “Semiconductor Industry Development in Taiwan,” 2005, 1143.

²⁰ Fuller, Adkinwande, and Sodini, “Leading, Following or Cooked Goose?” 2003, 7–8.

²¹ Amsden and Chu, *Beyond Late Development*, 2003, 107.

²² Leng, “Cross-Strait Economic Relations,” 2017, 152.

²³ Amsden and Chu, *Beyond Late Development*, 108–9.

assembly facilities in South Korea in the 1960s and 1970s, seeking to use low-cost Korean labor. By the late 1970s, Korean firms had begun to climb the semiconductor value chain, and wages increased. By the 1980s, companies like Samsung and Hyundai had emerged as serious competitors due to their narrow focus on the DRAM market. The South Korean government also established industrial estates for semiconductor production, housed state-sponsored research institutes (such as the Electronics and Telecommunication Research Institute) on these estates, used import restrictions to protect the market share of domestic firms, and limited foreign direct investment (except for joint ventures).²⁴ In spite of a worldwide recession in 1985, these firms were able to continue to invest in their manufacturing facilities, allowing them to remain competitive during a downward cycle in the market.²⁵

However, unlike Japanese firms, Korean firms were not able to rely on within-company or domestic demand to inform product development and instead invested heavily in advanced manufacturing processes. These investments were informed by another unique feature of the Korean industry, the presence of large industrial conglomerates known as *chaebols*.²⁶ Competition among the leading *chaebols* (Samsung, Hyundai, and LG) precipitated expansion and upgrading that proved faster than typical industry timelines.²⁷ Over time, the South Korean government pursued tariff reductions, provided preferred interest rates, offered subsidies for research and development, and sponsored pre-competitive research that led to breakthroughs. Finally, the industry benefited from the memory chip dispute between Japan and the United States: in the late 1980s and early 1990s, as Japanese firms reduced their worldwide production in accordance with the negotiated agreement, South Korean firms filled part of that demand.²⁸

Why Can't China Make Semiconductors?

As shown in VerWey (2019a), China's semiconductor industrial plans have lacked defined goals and clear implementation strategies, and have been hampered by bureaucratic redundancies. Relying heavily on state-owned enterprises (SOEs), these plans have been hindered by poor management, production inefficiencies, and a level of support from the state that resulted in profligate spending.²⁹ In particular, the SOEs lack absorptive and innovative capacity, producing chips that fail to gain commercial traction.³⁰ In contrast, the developmental trajectories of the Japanese, South Korean, and Taiwanese semiconductor industries share similar themes: a defined goal that featured several large firms targeting a subset of the worldwide semiconductor market (memory chips and foundry services); using government support to bolster human capital; and taking advantage of technology transfer and spillovers.

²⁴ Amsden, *Asia's Next Giant*, 1989, 82–83.

²⁵ Cho, Kim, and Rhee, "Latecomer Strategies," 1998, 499.

²⁶ Choi, "On Linsu Kim's Imitation to Innovation," 2007.

²⁷ Cho, Kim, and Rhee, "Latecomer Strategies," 1998, 499–500.

²⁸ Cho, Kim, and Rhee, "Latecomer Strategies," 1998, 500.

²⁹ Fuller, *Paper Tigers, Hidden Dragons*, 2016, 118.

³⁰ Fuller, "Limited Catch-Up in China's Semiconductor Industry," 2019, 442.

China's current plans look more sustainable, but still rely heavily on well-funded but poorly directed SOEs that benefit from a market that lacks true competition. At the same time, some of the larger challenges that hindered previous development, such as a dearth of human capital, remain unaddressed. This section will discuss issues including strategic direction (or lack thereof), funding, human capital, and one challenge that Japan, Korea and Taiwan did not face: U.S. export controls.

China's Challenges I: An Inability to Allocate Funds Efficiently and Strategically

China's investment in the development of a commercially viable domestic semiconductor industry is already in the hundreds of billions of dollars. However, the quantity of the capital that has been made available through the years has been smaller than advertised, has not been efficiently allocated, and frequently is not sustained at the levels needed to support technological breakthroughs over time.

National, provincial, and municipal IC funds are an integral part of China's strategy for developing its semiconductor industry. Endowed with close relationships to state-owned banks, these funds have engaged in global investments in an attempt to buy technologies that will allow China to catch up with the industry's leaders. One estimate from the Semiconductor Industry Association put the amount of money raised by just provincial and municipal IC funds since 2014 at \$80 billion.³¹ Yet, in spite of these numbers, funds frequently overlap with each other, engage in schemes to inflate the true value of their investments, and create redundancies.

Chinese strategic plans have frequently incorporated the use of state funding to partner with foreign firms in an attempt to foster knowledge spillovers. China's attempts to establish viable semiconductor manufacturing facilities in the 1990s (known as Projects 908 and 909) failed to absorb technologies that were acquired specifically to assist in their process engineering. As a result, these facilities achieved volume yields only after years of delay and failed to bring products to market that had commercial appeal.³² Notably, a joint venture between the Chinese SOE Huahong (\$500 million, 71.4 percent) and Japan's NEC (\$200 million, 28.6 percent) failed to result in the knowledge spillovers that the ninth five-year plan (FYP) had hoped for, as the Japanese company kept a close hold on even the mature technologies they were manufacturing.³³

Tax breaks, which offered the IC industry zero import duties along with a reduction in China's value-added tax (VAT) from 17 to 3 percent, also failed to promote domestic growth. In fact, more than half of the VAT tax breaks ended up going to foreign firms.³⁴ Such incentives have also been

³¹ USTR, *Section 301 Report*, 2018, 92, 94.

³² See part I of this series for an extended discussion of Projects 908 and 909.

³³ Fuller, *Paper Tigers, Hidden Dragons*, 2016, 124–25.

³⁴ Fuller, "Limited Catch-Up in China's Semiconductor Industry," 2019, 406.

subject to challenges before the World Trade Organization—notably in 2004, when China agreed to eliminate VAT refunds and phase out semiconductor-related tax rebates by 2005.³⁵

At the subnational level, government promotion of the IC industry has proved no more effective. Provincial and municipal leaders in China do not have a good track record of coordinating with national leaders, leading to redundancies that waste money or bring products to market in quantities that outpace demand.³⁶ In the 1990s, some local governments offered cheap land and subsidies in the hope that MNCs would invest in their regions. While they were successful in attracting some investments, the anticipated development of a fully integrated semiconductor supply chain was not realized. Instead, foreign companies acquired the fabrication facilities of several fledgling Chinese semiconductor manufacturers who had overexpanded. There were also allegations of fraud at the local level as officials sought to meet their targeted industrial investment numbers.³⁷

China's Challenges II: An Inability to Cultivate and Retain Human Capital

Foreign acquisitions, joint ventures with leading MNCs, and large R&D budgets are all designed to facilitate the generational leapfrogging that will be necessary for China to achieve its stated goals and catch up with the semiconductor industry's leaders. But China's ability to take advantage of these strategies is hampered by a persistent lack of highly skilled labor, a chronic problem that holds back the industry's overall progress. Because Chinese-headquartered semiconductor firms were not considered commercially viable until recently, Chinese electrical engineers who wanted to engage in the most advanced work in the field studied and worked abroad or for foreign firms with facilities in China. While not limited to semiconductor engineers specifically, recent analysis puts the size of China's scientific diaspora at 400,000 scientists and scholars.³⁸

Knowledge spillovers are essential to China's semiconductor industry strategy, but are contingent on human capital that is capable of understanding and employing said spillovers. Knowledge spillovers frequently take the form of learning by doing. In particular, learning contributes to growth if experience with current-generation products helps workers produce more advanced products.³⁹

In the semiconductor industry, knowledge spillovers take the form of process engineering research and development, an iterative process by which companies discover what manufacturing processes are effective as they fabricate chips. Related research into the facilities that build chips shows that decreasing semiconductor feature size is associated with increasing the time needed to build fabrication facilities and that the more domestic experience firms have, the easier it is to build

³⁵ USTR, "U.S. and China Resolve WTO Dispute," 2004.

³⁶ Wübbecke et al., *Made in China 2025*, 2016, 26.

³⁷ Fuller, "Limited Catch-Up in China's Semiconductor Industry," 2019, 410.

³⁸ Ding, "Deciphering China's AI Dream," March 2018, 20.

³⁹ Irwin and Klenow, "Learning-by-Doing Spillovers," 1994.

facilities.⁴⁰ However, there remains a dearth of skilled engineers in the country, meaning that China cannot take advantage of learning-by-doing spillovers to develop increasingly advanced products.⁴¹ In essence, the failure of China's FYPs has condemned the semiconductor industry to reinvent the wheel over and over again.

China's Challenges III: U.S. Export Controls

The efficacy of the U.S. export control regimes on semiconductor manufacturing equipment is questionable, though the controls may have sharpened China's resolve to develop a viable domestic industry. The United States has imposed controls on exports from China related to semiconductors and semiconductor manufacturing equipment in various forms since the Cold War. These controls, which are administered by two agencies—the U.S. Department of Commerce's Bureau of Industry and Security, and the Department of State's Directorate of Defense Trade Controls—specifically focus on dual-use technologies. Dual-use technologies, including semiconductors, are those that potentially have both commercial and military applications. Acting under the auspices of the North Atlantic Treaty Organization's (NATO) Coordinating Committee for Multilateral Export Controls (CoCOM), the United States attempted to multilateralize these export controls on semiconductor manufacturing equipment. Throughout the 1970s and 1980s CoCOM blocked exports of advanced semiconductor technology to China, though China did not have the technical ability to make use of such equipment in any case.⁴²

After CoCOM's dissolution in 1994, its successor, the 1996 Wassenaar Arrangement on Export Controls for Conventional Arms and Dual-Use Goods and Technologies (Wassenaar Arrangement) attempted to continue these controls, though many of the signatories' commitments became voluntary. Nonetheless, a U.S. government report from 2002 found that “the stated practice of U.S. export agencies has been to keep China two generations behind state of the art semiconductor production capabilities.”⁴³ This had a cooling effect on China's ability to partner with some leading U.S. firms. Notably, when the Chinese firm Huahong was considering which joint venture partner to select in the late 1990s under the auspices of Project 909, it passed over bids from Rockwell and IBM out of fear they would not be allowed to export the necessary equipment, opting to partner with Japan's NEC instead.⁴⁴

However, some research indicates that U.S. export controls did little to handicap the Chinese industry's development, for two reasons.⁴⁵ First, the semiconductor manufacturing equipment sought by Chinese firms in the 1990s and early 2000s was not advanced, meaning it did not rise to

⁴⁰ Salomon and Martin, “Learning, Knowledge Transfer, and Technology Implementation Performance,” 2008.

⁴¹ Notable exceptions are Huahong and SMIC, both of which recruited talented returnee experts to run their operations. See Fuller, *Paper Tigers, Hidden Dragons*, 2016, 126, 131–32.

⁴² Mays, “Rapid Advance,” 2016, 73.

⁴³ GAO, *Rapid Advances in China's Semiconductor Industry*, 2002, 2-3.

⁴⁴ Fuller, “Ladders out of Chains,” 2005, 260.

⁴⁵ Mays, “Rapid Advance,” 2016, 324.

the level of export-controlled goods. Second, much of the equipment that was restricted by the United States was not restricted by other countries in Europe and Japan, making it relatively easy for Chinese purchasers to work around U.S. export controls. For example, neither U.S. nor multilateral export controls affected the ability of Lucent Technologies (U.S.) to engage in a joint venture with Huajing (China) under the auspices of China's Project 908 in the mid-1990s.⁴⁶

A 2002 study by the U.S. General Accounting Office (GAO, now known as the Government Accountability Office) confirmed research finding that U.S. controls were ineffective, noting, "Wassenaar has not affected China's ability to obtain semiconductor manufacturing equipment because the U.S. is the only member of this voluntary agreement that considers China's acquisitions a cause for concern."⁴⁷ A follow-up study by the GAO examined the impact of the Department of Commerce's Validated End-User program, which allowed pre-screened Chinese firms (including SMIC, China's most advanced foundry) to import some semiconductor manufacturing equipment and materials. GAO's study found that Commerce had limited ability to ensure that these items' end uses were nonmilitary, though the ability to procure these goods certainly assisted in the Chinese industry's commercial development.⁴⁸ While U.S. export controls may have only marginally slowed the Chinese industry's development, when combined with the aforementioned human capital and funding challenges, China's semiconductor industry remains one to two generations behind world-leading firms.

How Sustainable Is China's Commitment to the Vision Outlined in the National IC Plan and MIC2025?

Given the mixed record of China's past and current semiconductor industrial plans, a final question naturally arises: how motivated is China to pursue the domestic development of this industry and what are its prospects for success this time? The short answers are that China is highly motivated to develop a domestic semiconductor industry for economic and national security reasons—and that this iteration represents its best opportunity to succeed yet.

China's Motivation I: Economic Interest

The volume and value of chips that China imports far outpace the current amount produced domestically by Chinese-headquartered firms. Between 2013 and 2017, China's balance of trade in ICs widened from a \$144 billion deficit to a \$193 billion deficit, a trend that will likely continue as a greater number of chips are used in more final goods.⁴⁹ These imports remain necessary, given the ongoing gap between domestic consumption and production (figure 1), with the gap between the former and latter growing every year from 1999–2015.⁵⁰

⁴⁶ Mays, "Rapid Advance," 2016, 146.

⁴⁷ GAO, *Rapid Advances in China's Semiconductor Industry*, 2002, 2–3.

⁴⁸ GAO, *Validated End-User Program*, 2008, 1.

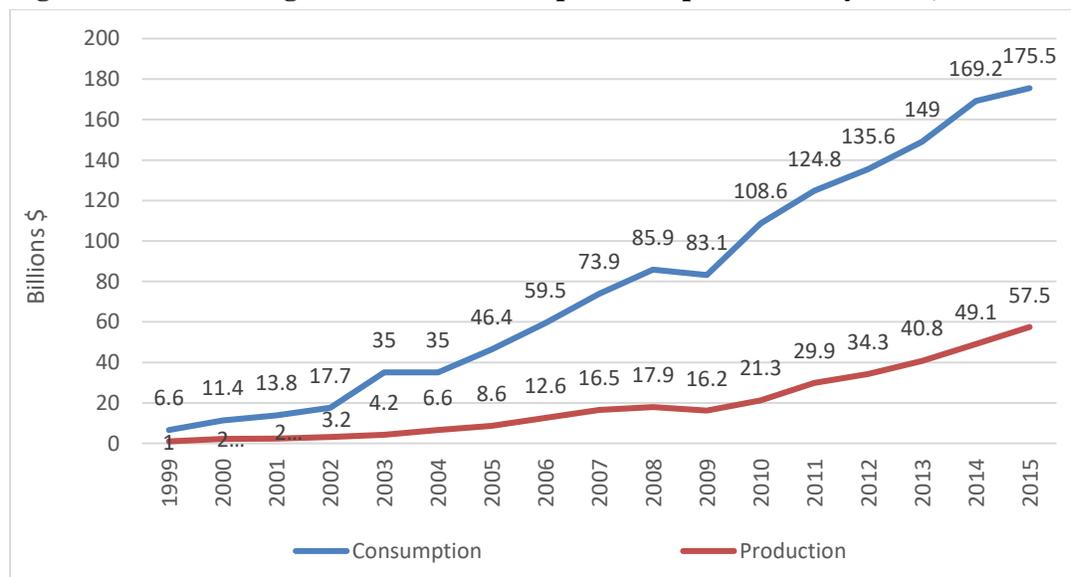
⁴⁹ IHS Markit, *Global Trade Atlas*, HTS 8542 (accessed November 16, 2018).

⁵⁰ PwC, "China's Semiconductor Market," 2017.

Indeed, as more finished goods incorporate chips, China’s reliance on imports of chips may also prove to be a bottleneck for other industrial plans that it has announced. To take just one example, the success of MIC2025’s plans for developing domestic new-energy vehicles is contingent on a consistent supply of the chips that will enable these goods. In 2015, 10.3 percent of worldwide consumption of semiconductors went in to the auto industry, and it is estimated that a hybrid electric vehicle can contain \$1,000 of semiconductor content totaling up to 3,500 semiconductors.⁵¹

One additional data point that highlights the economic importance China places on imports of semiconductors comes from the ongoing trade dispute between China and the United States. In response to the United States placing tariffs of 10–25 percent on \$250 billion in imports from China, the Chinese government instituted retaliatory tariffs on about \$113 billion in imports from the United States.⁵² Notably, although China imported about \$10 billion of chips from the United States in 2017, no imports of chips were on the retaliatory tariff list.⁵³

Figure 1: China’s integrated circuit consumption and production by value, 1999–2015



Source: PwC, “China’s Impact on the Semiconductor Industry: 2017 Update,” September 15, 2017.

In addition to China’s reliance on chips for its current industrial output, the development of a domestic industry has a bearing on its future economic performance. China’s State Council released a national strategy for artificial intelligence (AI) in July 2017, formally signaling the country’s focus on AI development as a future driver of economic growth and providing benchmarks for AI and AI-related industries.⁵⁴ As part of this strategy, China has recognized the

⁵¹ Coffin and Kim, “U.S. Firms Are Becoming Leaders in the Automotive Semiconductor Market,” 2017; Lawrence and VerWey, “The Automotive Semiconductor Market: Key Determinants,” 2019.

⁵² Rodriguez, “China Tariff Retaliation,” September 18, 2018.

⁵³ Crowell Moring, “Latest Trade Actions/Tariffs” (accessed December 4, 2018).

⁵⁴ Ding, “Deciphering China’s AI Dream,” March 2018, 7.

importance that hardware will play in training any potential AI; the government has “supported ‘national champions’ with substantial funding . . . and made long-term bets on supercomputing facilities” in furtherance of this goal.⁵⁵ China’s future aspirations in the quantum computing space are also contingent on hardware advances that the Chinese semiconductor industry has yet to supply.⁵⁶

Recent actions by the U.S. government highlight the exposure and dependence of some Chinese technology companies on imports of chips and have added momentum to China’s plans for the development of a domestic industry. In April 2018, the U.S. Department of Commerce issued an announcement banning U.S. firms from doing business with the Chinese telecom company ZTE because it violated sanctions against Iran and North Korea. This decision, which was ultimately rescinded in July 2018, effectively put ZTE out of business overnight and threatened to undermine the rollout of fifth-generation (5G) cellular devices in China.⁵⁷ The Chinese facial recognition camera maker Hikvision, which is dependent on components from U.S. chip firms like Intel and Nvidia, may face a similar ban due to their product’s use in surveillance systems used to monitor Uighur citizens in China’s Xinjiang province.⁵⁸ In addition, a 2019 decision by the United States government that would ban U.S. semiconductor firms from engaging in business with Huawei and its chip design subsidiary HiSilicon also highlighted the Chinese industry’s reliance on partnerships with international firms and may reinforce the Chinese government’s commitment to develop “semiconductor independence.”⁵⁹

Actions like these have raised alarm among Chinese firms that rely on imports, with some calling the ZTE export ban a “Sputnik moment” that highlights how import-dependent some of China’s economic success stories are. Such moves will heighten China’s commitment to developing a domestic chip industry.⁶⁰ In the wake of the ZTE ban, the Chinese conglomerate Alibaba, among others, was said to have accelerated its investment in domestic semiconductor development.⁶¹

China’s Motivation II: National Security

China’s national security motivations for semiconductor independence are twofold: trustability and technical advantage. In general, countries prefer to know the provenance of the chips that they are procuring for use in national security systems. Additionally, militaries worldwide have started to incorporate chips in more and more goods. As the number of chips in military systems (and in the phones and computers that they operate on) proliferates, so too have the opportunities to potentially build backdoors into those systems for espionage purposes. This possibility has

⁵⁵ Ding, “Deciphering China’s AI Dream,” March 2018, 4.

⁵⁶ Kania and Costello, “Quantum Hegemony,” 2018, 4.

⁵⁷ Yuan, “ZTE’s Near-collapse,” June 10, 2018.

⁵⁸ Feng, “Chinese Group Faces Ban.” November 18, 2018.

⁵⁹ Timberg and Albergotti, “Will U.S. War on Huawei Help China?” 2019.

⁶⁰ Yuan, “ZTE’s Near-collapse,” June 10, 2018.

⁶¹ Bergen, “Alibaba Producing Its Own Chips,” October 25, 2018.

motivated China to develop chips domestically for military use for decades.⁶² It continues to motivate China to this day, particularly following revelations about the U.S. National Security Agency's PRISM program, which directly implicated U.S. chip firms, including Intel, Qualcomm, and IBM.⁶³

Along with the desire to know the origin of chips used in military hardware is the desire to secure production of the most advanced chips so that the military may have a technological and competitive edge. This strategy has been outlined in various formats by the People's Liberation Army since at least 2001. The PLA's recent focus on information warfare continues to highlight the importance placed on chip hardware.⁶⁴

What Are China's Prospects for Success with Its Current Semiconductor Industrial Plans?

Informed by the goals outlined above and its experience with previous failed semiconductor industrial plans, China's current attempt to develop a domestically viable semiconductor industry features national champions focused on recruiting highly skilled engineers, leveraging partnerships with foreign firms, and pursuing defined sectoral goals. This section will first discuss China's designated "national champions" before moving on to analyze the sector specific focus of their current plans.

Defined Goal I: National Champions

Semiconductor Manufacturing International Corporation (SMIC) is a Shanghai-headquartered foundry that currently operates the largest and most advanced chipmaking facilities in China. Though it did not claim direct ties to the Chinese government when it was founded in 2000, recent developments have made it clear that the Chinese government sees SMIC as its best chance to develop a commercially viable Chinese-headquartered semiconductor manufacturer.⁶⁵ Since its founding, SMIC has adopted a hybrid model, leveraging investments from both the Chinese government and private international firms, as well as market-oriented partnerships. This combination of investments and partnerships has endowed SMIC with the largest manufacturing capacity of any chipmaking firm in China.

Recently, through a partnership with Huawei (China), the fabless design company Qualcomm (U.S.), and IMEC (Belgium), SMIC achieved the technical prowess necessary to develop 14-nanometer chips that are near the industry's leading edge.⁶⁶ SMIC has also been helped by other

⁶² Mays, "Rapid Advance," 2016, 64.

⁶³ Majerowicz and Aguiar de Medeiros, "Chinese Industrial Policy," 2018, 8.

⁶⁴ Majerowicz and Aguiar de Medeiros, "Chinese Industrial Policy," 2018, 5.

⁶⁵ Fuller, *Paper Tigers, Hidden Dragons*, 2016, 131–45.

⁶⁶ Fuller, "Limited Catch-Up in China's Semiconductor Industry," 2019, 414; Merritt, "SMIC, Qualcomm Deal," July 23, 2015.

ongoing partnerships with Qualcomm, which has provided money, expertise and engineers since it first made inroads in China in the 1990s.⁶⁷ This partnership has not been without controversy in the governments of the United States (given SMIC's ties to the Chinese government) and in China (where Qualcomm's patent licensing fees have resulted in large fines and settlements).⁶⁸ Both sides have become more mutually skeptical in recent years, as the National IC Fund (under the auspices of Sino IC Capital) bought a 17 percent stake in SMIC in 2015, and Chinese state bureaucrats occupied the majority of SMIC's board.⁶⁹

While SMIC has been focused on developing domestic manufacturing capacity, Tsinghua Holdings (and its subsidiary Tsinghua Unigroup), a wholly owned subsidiary of the state-led Tsinghua University, has been designated the lead domestic and international investor in China's IC industry. Tsinghua Holdings maintains a 51 percent stake in Tsinghua Unigroup, which received a \$1.6 billion investment from the National IC Fund.⁷⁰ Both entities share the same goal of accelerating the development of China's IC industry through a model of "international acquisition and indigenous innovation."⁷¹ From 2014 to 2016, Tsinghua Holdings and its subsidiaries made offers of various sizes for stakes in U.S. firms. The largest of these, a \$23 billion bid for Idaho-based memory chipmaker Micron Technology, was shut down based on national security concerns raised by the Committee on Foreign Investment in the United States (CFIUS).⁷²

Defined Goal II: Sectoral Focus

Though Tsinghua Unigroup's bid for Micron failed to gain regulatory approval, the offer itself demonstrates another improved facet of China's latest plan: clearly identified sectoral goals. In particular, China has focused its attention on the memory chip market and the smartphone market, two areas where there is clear commercial demand.

After failing to secure meaningful acquisitions of industry-leading memory chipmakers, Tsinghua Unigroup focused its attentions on consolidating its holdings in the Chinese memory market. Most notably, it purchased a 5 percent stake in SMIC while also investing \$24 billion in one of China's three major memory chip initiatives, Yangtze Memory Technologies Co. (YMTC), helmed by a former chief operating officer of SMIC.⁷³ Memory chips have been specifically, and logically, targeted as an area of promise by the Chinese government. Attractive traits of memory chips include high-volume, high-yield runs; faster production cycles (meaning errors can be identified and corrected more quickly); lower technical barriers to entry than other types of ICs; and growing domestic commercial demand.

⁶⁷ Ma, "Qualcomm's China Conundrum," November 14, 2018.

⁶⁸ Barboza, "U.S. Tech Giant Backing China's Ambitions," August 4, 2017.

⁶⁹ Fuller, "Limited Catch-Up in China's Semiconductor Industry," 2019, 429.

⁷⁰ USTR, *Section 301 Report*, 2018, 85.

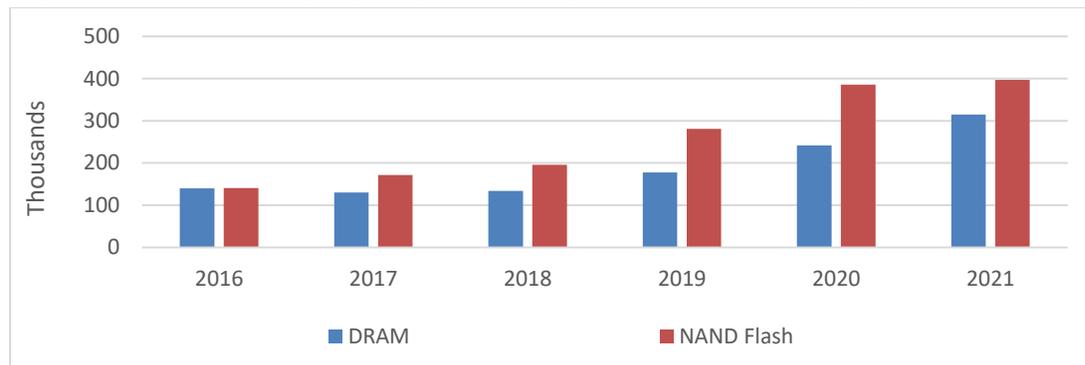
⁷¹ USTR, *Section 301 Report*, 2018, 85.

⁷² Baker and Roumeliotis, "Micron-Tsinghua Deal Not Possible," July 21, 2015.

⁷³ Fuller, "Limited Catch-Up in China's Semiconductor Industry," 2019, 422–28.

In addition to YMTC, Innotron and Fujian Jinhua Integrated Circuit Company have been targeted under the National Memory Base Storage Project, which aims to leverage these three new chip fabricators through a series of joint ventures with leading memory chipmakers such as Samsung, SK Hynix, and Intel. As figure 2 shows, China’s already surging capacity is expected to ramp up still further as the three chip fabricators begin volume production in 2019.⁷⁴

Figure 2: China memory capacity forecast, by 300-mm wafer starts per month⁷⁵



Source: Du, “2018 Outlook and Drivers,” SEMI, June 2018, 19.

China’s effort to develop and bolster its smartphone chipmakers is a microcosm of its overall industrial planning. Using a narrowly defined market with existing commercial appeal and growing domestic demand, Chinese firms are attempting to acquire the technology and intellectual property needed to create chips domestically, while simultaneously incentivizing firms to engage in joint ventures with mainland companies. One of the clear targets of this effort is Taiwan’s leading smartphone chipmaker, MediaTek. Motivated by a desire to make inroads with the high-tech industry in China, in 2014, MediaTek invested \$489 million in a joint fund, SummitView Capital. Run by the Shanghai city government, SummitView counts SMIC and Tsinghua Holdings as other investors. At the same time, Tsinghua Unigroup was engaging in mergers and acquisitions designed to accelerate Chinese smartphone chip development at the expense of MediaTek. To that end, Tsinghua Unigroup acquired RDA for \$1 billion and Spreadtrum Communications (which went on to acquire several companies of its own) for \$1.78 billion.⁷⁶

Defined Goal III: China’s Attempts to Address Its Human Capital Deficit

China’s inability to foster a domestic workforce capable of absorbing and employing the knowledge necessary to develop semiconductors has limited the effectiveness of its industrial plans in the past. Recognizing the importance of a skilled workforce, the Chinese government has recently instituted a series of programs designed to fill this gap.

China’s efforts to develop human capital have included initiatives to educate students at leading institutions worldwide and motivate top research talent abroad to come to China. Currently, about

⁷⁴ See later discussion on current U.S. Commerce Department actions targeting Fujian Jinhua, which may change these forecasts.

⁷⁵ Du, “2018 Outlook and Drivers,” 2018, 16.

⁷⁶ Leng, “Cross-Strait Economic Relations,” 2017, 165–66.

25 percent of graduate students in science, technology, engineering, and mathematics (STEM) in the United States are Chinese citizens, and the worldwide size of China's scientific diaspora exceeds 400,000 researchers.⁷⁷ Recognizing that not all Chinese students studying internationally will return home, the Chinese government instituted the Thousand Talents program in 2008 to attract foreign researchers and incentivize the return of Chinese scientists from abroad, particularly those with a background in STEM.⁷⁸ The program has seen mixed success, with estimates of returned recruits varying from 2,629⁷⁹ to "over 7,000."⁸⁰ Moreover, analysis of the quality of these recruits indicates that many are not among the "best and brightest."⁸¹

In spite of these mixed results, some high-profile scientists have returned to China, particularly in the quantum computing and artificial intelligence fields.⁸² These successes have raised concerns in the United States and other countries, with the U.S. intelligence community interpreting the Thousand Talents Program as a part of an effort to "transfer, replicate and eventually overtake U.S. military and commercial technology."⁸³ Further evidence of Chinese efforts to cultivate STEM talent came from an October 2018 report from the Australian Strategic Policy Institute. The report found that more than 2,500 Chinese military-affiliated scholars had visited universities in technologically advanced countries in the past decade while working in fields such as "quantum physics, signal processing, cryptography, navigation technology and autonomous vehicles."⁸⁴

Given that semiconductor technology is fundamental to the technologies just mentioned, China's efforts to recruit semiconductor-specific talent are not surprising, though they have met with limited high-profile successes so far and have led to few systemic changes. Taiwan's leading foundries, TSMC and UMC, have both seen company leaders recruited to the mainland. In 2017, the former CEO of UMC joined Tsinghua Unigroup, while two of TSMC's leading researchers joined SMIC in the same year.⁸⁵ China has also managed to attract more than 1,300 senior engineers from Taiwan since 2014, lured by 50 percent pay raises, subsidized apartments, and the promise of eight free trips home per year.⁸⁶

Innotron and YMTC, two of the three new memory chip makers funded in China's latest National IC Plan, have sought to poach talent from existing non-Chinese memory industry leaders. Innotron attempted to recruit Yukio Sakamoto, former CEO of Japanese-based Elpida Memory (now owned

⁷⁷ Brown and Singh, *China's Tech Transfer Strategy*, 2018, 3; Schiermeier, "China at a Crossroads," March 6, 2018.

⁷⁸ Jia, "China's Plan to Recruit Engineers," January 17, 2018.

⁷⁹ Capaccio, "U.S. Faces Threat from China Tech Takeover," June 22, 2018.

⁸⁰ Kania and Costello, "Quantum Hegemony," 2018, 11.

⁸¹ Cao, "China's Brain Drain at the High End," 2008.

⁸² Ding, "Deciphering China's AI Dream," March 2018, 19; Kania and Costello, "Quantum Hegemony," 2018, 11.

⁸³ Capaccio, "U.S. Faces Threat from China Tech Takeover," June 22, 2018.

⁸⁴ Joske, "Picking Flowers, Making Honey," October 30, 2018.

⁸⁵ Hwang, "Computational Power and AI," 2018, 26. Note, however, that one of the recruits from TSMC is a SMIC board member and likely does not contribute know-how to day-to-day operations.

⁸⁶ Lee, "China Lures Chip Talent," September 4, 2018.

by Micron) and 1000 Taiwanese, Korean, and Japanese engineers he claimed to be able to bring with him, without success.⁸⁷ YMTC announced a similar plan to recruit 1,000 engineers from Samsung and SK Hynix, the other leading memory chipmakers in the world, though it is not clear whether this initiative will succeed.⁸⁸ By some metrics of innovation, however, there are signs that China's initiatives are working in a general way in the STEM field. China saw over one million patent applications in 2015, was second only to the U.S. in academic research papers published in peer-reviewed journals, and awarded nearly 1.3 million STEM degrees in 2014 (compared with slightly over 500,000 in the United States).⁸⁹

Remaining Questions Facing China's Semiconductor Industry

In spite of the advances China has made in acquiring technology, investing in existing and new chipmaking capabilities up and down the value chain, and promoting human capital growth at an advantageous time in the industry's growth cycle, several questions remain about the viability of this iteration of its semiconductor industrial plan.

Catching Up Only to Be Left Behind?

In 2016, China had over 170 wafer fabs and an additional 123 ATP facilities.⁹⁰ In addition, China's gap with leading international semiconductor firms has consistently narrowed over time (table 1) as both the quantity and quality of chips produced in China has improved. On the surface, these trends compare favorably with those in the United States, which had roughly 70 such facilities according to one 2017 analysis,⁹¹ and likely exceeds the number of facilities in any other country.

Table 1: China's semiconductor technology gap with leading international semiconductor firms, 1979–2018

Year	Domestic Chinese technology	Years behind
1979	25 mm to 30 mm wafers	16
1986	5 micron	14
1995	3 micron	19
1998	0.8 micron	10
2003	0.13 micron	1 to 2
2012	40 nm	1 to 2
2018	28 nm	1 to 2

Source: Author's compilation from Fuller, *Paper Tigers, Hidden Dragons*, 2016.

However, a quantitative analysis of the number of facilities overstates China's competitiveness and progress for two reasons. First, there is no concordance among data sources. Some data sources on wafer fabrication facilities count each process line in a particular building as a separate facility, while other data sources count each building, regardless of the number of process lines housed

⁸⁷ Fuller, "Limited Catch-Up in China's Semiconductor Industry," 2019, 434.

⁸⁸ Fuller, "Limited Catch-Up in China's Semiconductor Industry," 2019, 435.

⁸⁹ Brown and Singh, *China's Tech Transfer Strategy*, 2018, 13.

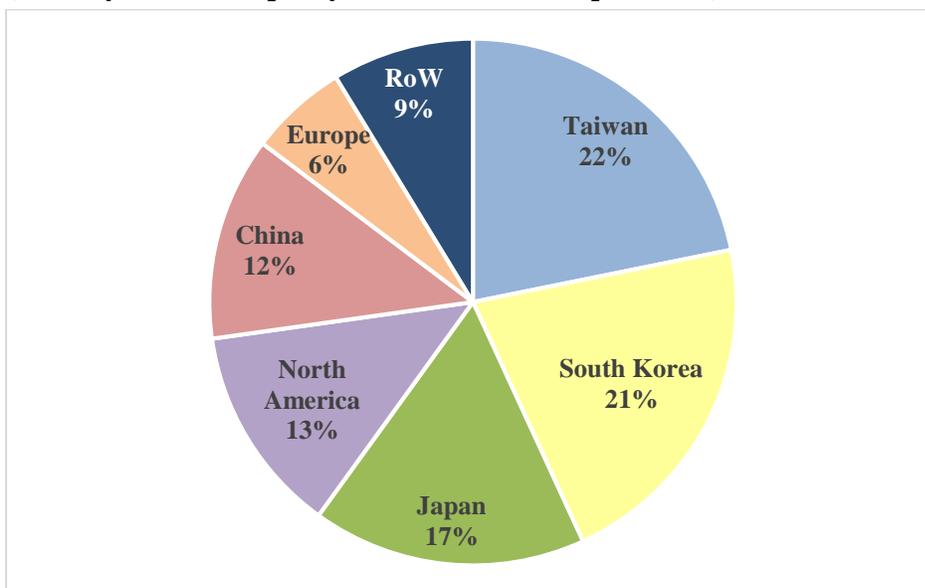
⁹⁰ PwC, "China's Semiconductor Manufacturing," 2017.

⁹¹ Fried, "Computer Chips Made in the USA," September 5, 2018.

within, as one production facility. Still other data sources count back-end ATP lines as part of the manufacturing process.

The second reason that these numbers are less impressive than they may seem is that even as the technology gap has narrowed, international firms retain a meaningful lead by most other metrics. As figure 3 shows, at the end of 2018, China's monthly installed wafer capacity of 12 percent lagged far behind that of Taiwan (22 percent), South Korea (21 percent) and Japan (17 percent). These raw numbers demonstrate installed capacity at fabrication facilities and illustrate the magnitude of the challenge faced by Chinese firms. However, they do not show the degree of competition Chinese firms face.

Figure 3: Global wafer capacity as of December 2018, share by region (monthly installed capacity in 200-mm wafer equivalents)



Source: IC Insights, "Taiwan Maintains the Largest Share of Global IC Wafer Fab Capacity," February 14, 2019.

Chinese semiconductor firms that seek to develop commercially viable advanced chips must also contend with competition from leading firms internationally. As tables 2 and 3 show, China's plans to develop semiconductor firms to compete in the foundry services and memory chip businesses may be less viable than they appear on the surface. Part of China's plan to develop a commercially viable domestic semiconductor industry relies on joint ventures, which are intended to promote both knowledge transfer and technology spillovers. To that end, with Chinese encouragement, leading foundry firms like TSMC (Taiwan), UMC (Taiwan), and GlobalFoundries (U.S.) have all opened facilities in China. By the end of 2018, China's starts per month of 300 mm wafers stood at roughly 415,000, of which 195,000 (47 percent) came from fabrication facilities that were majority-owned by non-Chinese headquartered firms.

Looking even more closely at the numbers, it is clear that most of these facilities are not manufacturing chips that constitute the world's leading edge. In 2017, SMIC, China's largest and most advanced domestic foundry, had a capacity of roughly 229,000 200 mm wafer starts per month, 95,000 300 mm wafer starts per month, and its most advanced process technology node

was 28 nm technology.⁹² In contrast, TSMC, Taiwan's leading foundry, has an announced monthly fabrication capacity of over one million 300 mm wafer starts, brought 28nm technology to the market in 2011, and has reached volume production of 7 nm chips as of 2018.⁹³ Put simply, SMIC, which is one of China's designated national champions and has access to all the resources any Chinese firm could reasonably hope to enjoy, is developing fabrication facilities that will produce chips that are five to six years behind the industry's leading edge at 10 percent of the volume of the world's leading firm.

Table 2: Forecasted Chinese foundry capacity, 300 mm wafers⁹⁴

Company name	Facility location	Majority ownership?	Total targeted WSpM*	Status	Process node(s) targeted
CanSemi	Guangzhou	Domestic	40,000	Under construction	180–130 nm
GlobalFoundries	Chengdu	International	85,000	On hold	22 nm
Huahong Group (Shanghai Huali Microelectronics (HLMC))	Shanghai	Domestic	35,000	Current	40 nm, 28 nm
Huahong Group (Shanghai Huali Microelectronics (HLMC))	Shanghai	Domestic	40,000	Under construction	28 nm, 14 nm
Huahong Group	Wuxi	Domestic	40,000	Under construction	90 nm, 65 nm
Powerchip (Hefei Jinghe)	Hefei	International	40,000	Under construction	150 nm, 110 nm, 90 nm
SMIC	Beijing - B1	Domestic	50,000	Current	28 nm, 14 nm
SMIC	Beijing - B2	Domestic	35,000	Current	28 nm, 14 nm
SMIC	Shanghai	Domestic	20,000	Current	40 nm, 28 nm, 14 nm
SMIC	Shanghai	Domestic	35,000	Under construction	14 nm
TSMC	Nanjing	International	20,000	Current	16 nm
UMC	Xiamen	International	50,000	Current	40 nm, 28 nm
XMC (Wuhan Xinxin)	Wuhan	Domestic	30,000	Current	32 nm

* WSpM = wafer starts per month.

Source: Author's compilation; SEMI World Fab Forecast.

China's plans to promote the development of memory chip companies face challenges similar to those in the foundry services business. As table 3 shows, Chinese memory chip companies have

⁹² SMIC, "2017 Corporate Social Responsibility Report," June 2018.

⁹³ TSMC, "Fab Capacity" (accessed March 18, 2019),

https://www.tsmc.com/english/dedicatedFoundry/manufacturing/fab_capacity.htm; Shilov, "TSMC: First 7nm Chips," October 9, 2018.

⁹⁴ See appendix B for a complete list of current and forecasted Chinese memory and foundry capacity by 200 mm and 300 mm wafer starts per month.

announced ambitious plans that, on the surface, dwarf those of their international competitors. However, currently most production of memory chips in China is coming from fabrication facilities owned by foreign firms Intel (U.S.), Samsung (South Korea), and SK Hynix (South Korea), which have all expanded or are in the process of expanding their Chinese facilities. In contrast, no Chinese-owned companies have yet reached commercial production.

Table 3: Forecasted Chinese memory chip capacity, 300 mm wafers⁹⁵

Company name	Facility location	Majority ownership?	Total targeted WSpM*	Status	Process node(s) targeted
Innotron (ChangXin Memory Technologies)	Hefei	Domestic	125,000	Under construction	19 nm, 17 nm
Intel	Dalian	International	70,000	Current	65 nm
JHICC (Fujian Jinhua)	Jinjiang	Domestic	60,000	On hold	22 nm
Samsung	Xi'an	International	200,000	Current (expansion)	20 nm
SK Hynix	Wuxi	International	170,000	Current	22 nm
Tsinghua Unigroup	Nanjing	Domestic	200,000	Under construction	TBD
Tsinghua Unigroup	Chengdu	Domestic	300,000	Under construction	TBD
XMC (Wuhan Xinxin)	Wuhan	Domestic	115,000	Under construction	45 nm
YMTC	Wuhan	Domestic	300,000	Under construction	TBD

* WSpM = wafer starts per month.

Source: Author's compilation; SEMI World Fab Forecast.

China's plans for the National Memory Storage Base, which benefit from partnerships with South Korean semiconductor firms, stand to be undermined by those very firms. SK Hynix announced its intention to break ground on a new \$3 billion fab in South Korea in late 2018 and currently reports a capacity of 400,000 wafer starts per month at its facilities in South Korea.⁹⁶ Its main competitor, Samsung, announced a \$26.1 billion investment in its Pyeongtaek facility in two phases through 2017–18, an investment that is twice that of China's total National Memory Storage Base in Wuhan and at least three years more advanced in process technology.⁹⁷

In other words, by the time China's current domestic-owned memory chip (targeting roughly 885,000 wafer starts per month) and foundry services firms (targeting roughly 260,000 wafer starts per month) have reached full capacity around 2020 (an optimistic timeline), TSMC and Samsung

⁹⁵ See appendix B for a complete list of current and forecasted Chinese memory and foundry capacity by 200 mm and 300 mm wafer starts per month.

⁹⁶ Shilov, "Hynix to Build New Fab," July 30, 2018.

⁹⁷ Shilov, "Hynix to Build New Fab," July 30, 2018.

alone will have brought facilities on line that cumulatively produce 1.5 million 300 mm wafer starts per month at chip factories that are three generations more advanced than anything manufactured in China.⁹⁸

Galapagos Syndrome?

China's efforts to develop a domestic semiconductor industry may also result in an industry that fails to reach a commercial market beyond that of China itself. This phenomenon occurs when a country develops domestic products that fit a series of standards that do not necessary meet or adhere to the standards adopted outside of the country. Known as the Galapagos Syndrome, this approach to economic competitiveness is precisely what undermined Japanese mobile device manufacturers' competitiveness in the transition from second-generation (2G) to third-generation (3G) wireless device standards in the 1990s and early 2000s. These manufacturers developed products that met Japan's wireless and mobile data standards, but diverged from international standards, denying them additional markets.⁹⁹ This is already happening in China with the development of TD-SCDMA (mobile), WAPI (wireless LAN encryption), and AVD and CBHD (digital disc players) standards, all of which have limited support within China and no support outside of China.¹⁰⁰ China has also engaged in state-led procurement efforts designed to accelerate the development of technology intensive goods, notably with IC cards used in phone and transportation payments, which do not have a commercial market outside of the country and have limited appeal in-country.¹⁰¹

What Will Be the Effect of New Export Controls and Investment Restrictions?

China's prospects for developing a domestic chip industry must also contend with potential increased export controls and decreased foreign investment opportunities going forward. The suspicious circumstances following the attempted takeover of German semiconductor equipment maker Aixtron have eroded the ability of Chinese companies engaged in outbound FDI to complete new deals with semiconductor firms in Europe and the United States.¹⁰² One example is the pending acquisition of U.S.-based Lattice Semiconductor, a leader in the design of field-programmable gate array (FPGA) chips, involving a Silicon Valley private equity firm funded by the Chinese government. This deal was blocked by CFIUS in 2017,¹⁰³ as was the proposed acquisition of U.S. semiconductor testing company Xcerra Corp in early 2018.¹⁰⁴

In August 2018, the U.S. Congress passed the Foreign Investment Risk Review Modernization Act of 2018 (FIRRMA), which effectively removed the possibility of large Chinese mergers with and acquisitions of U.S. semiconductor firms for the foreseeable future. This new law will likely

⁹⁸ TSMC, "TSMC Breaks Ground on Fab," January 26, 2018.

⁹⁹ SIA, *Beyond Borders*, 2016, 25.

¹⁰⁰ Breznitz and Murphree, "Rise of China Tech Standards," 2013, 2.

¹⁰¹ Fuller, "Limited Catch-Up in China's Semiconductor Industry," 2019, 406.

¹⁰² Hanemann, "Chinese FDI in the US in 2018," June 19, 2018.

¹⁰³ Swanson, "Trump Blocks China Bid for Chipmaker," September 13, 2017.

¹⁰⁴ Roumeliotis, "U.S. Blocks Sale to Chinese Fund," February 22, 2018.

contribute to a broader slowdown in Chinese outbound mergers and acquisitions globally.¹⁰⁵ In September 2017 the European Union put forward a similar proposal, which imposed curbs on investments from China in particular sectors. Additionally, in 2018, Germany's main business lobbying group recommended that German firms re-assess their presence in China altogether.¹⁰⁶

In addition to investment restrictions, FIRMA also initiated a review by the U.S. government of exports of foundational and emerging technologies. This review may result in new export controls. The Bureau of Industry and Security, which administers part of the U.S. export control regime, specifically identified semiconductor manufacturing equipment as well as the semiconductors themselves as subjects of interest for future controls.¹⁰⁷ Given that semiconductor manufacturing equipment could conceivably be used to make chips for either commercial or military applications (dual-use applications), this restriction could be justified on national security grounds and would essentially be a return to similar export controls that the United States had in place until 2007.¹⁰⁸

The United States may act multilaterally to ensure that China cannot secure access to comparable technologies from other countries by using international export control forums such as the Wassenaar Arrangement and the Australia Group. This move could be particularly damaging given that China does not have the capability to manufacture key semiconductor fabrication equipment, and that companies like SMIC rely on imports of these products from countries like Japan and the Netherlands (where SMIC recently purchased the most advanced tool available for extreme ultraviolet lithography).¹⁰⁹

Additionally, the U.S. government has actively pursued prosecution of people who have attempted to export chips with civilian and military applications to China in an effort to block illicit technology transfer.¹¹⁰ One such enforcement action was against an individual who was convicted of attempting to export radiation-hardened ICs, which are used in a variety of military and aerospace systems, to China.¹¹¹ Recently the Bureau of Industry and Security, which blocked U.S. firms from doing business with ZTE in April 2018, instituted a similar ban against Fujian Jinhua, one of the three leading memory chipmakers China has supported under the auspices of the National Memory Storage Base initiative. The reason given for instituting the ban was Fujian

¹⁰⁵ Zhang, "China Goes on M&A Diet," January 24, 2017; Hanemann, "Chinese FDI in the US in 2018," June 19, 2018.

¹⁰⁶ Reuters, "China's Concern over EU Curb of Takeovers," September 18, 2017; Barkin, "German Firms Urged to Cut China Ties," October 31, 2018.

¹⁰⁷ *Federal Register*, "Review of Controls for Certain Emerging Technologies," November 19, 2018.

¹⁰⁸ Li, "Development of Chinese Semiconductor Industry," 2011, 68.

¹⁰⁹ Ting-Fang, "Chinese Chipmaker Takes Edge," May 15, 2018.

¹¹⁰ USDOJ, "2 Charged for Illegally Obtaining Chips," January 19, 2018; USDOJ, "Man Sentenced for Exporting Integrated Circuits," January 24, 2018.

¹¹¹ USDOJ, "Man Sentenced for Exporting Integrated Circuits," January 24, 2018.

Jinhua's intellectual property violations against Idaho-based Micron Technologies that threaten national security.¹¹²

How Will China Address Its Looming Talent Crunch?

China's weak record in cultivating, recruiting, and retaining international talent also raises questions about the viability of its current industrial plans. According to a recent report, China's semiconductor industry needs a total of 700,000 employees by 2020 if it is going to realize production of \$200 billion, but current statistics indicate a workforce of only 300,000.¹¹³ This workforce shortage of 400,000 has prompted both the Chinese government and firms to offer huge benefit packages in an effort to lure talent to the country with mixed success.¹¹⁴ In addition, it is not clear that the talent China has attracted thus far will provide the technical knowledge necessary to ensure its semiconductor industry develops into a sustainable and world-leading level. Some widely cited statistics about China's growing innovative prowess mask underlying weaknesses. Though China has filed the most domestic patents of any country over the past 10 years, more than 90 percent of patent owners stop paying for design patents after the fifth year, indicating that the quality of patents does not match the volume.¹¹⁵

Conclusion

China's plans to support the development of its semiconductor industry date to the 1950s. In spite of these repeated efforts, China's industry continues to lag behind the worldwide leaders. This article attempted to answer two questions: First, why can China still not make commercially viable advanced semiconductors? Second, what are China's prospects for success this time around? Poorly crafted and executed strategic plans, a lack of human capital, and other countries' export controls have all hampered the development of China's industry in the past. While ongoing challenges remain, China currently has the strategic planning, motivation, and funding available to ensure that its domestic industry eventually catches up with the worldwide leaders. This is cause for Chinese optimism, but several cautionary notes must be considered, including the timing of the industry's development relative to international competitors, new investment restrictions and export controls, and the quantity and quality of the human capital on which China's semiconductor industry relies.

More generally, the U.S. semiconductor industry is presented with a unique conundrum: China is both its most important customer and, if China's industrial plans are successfully realized, its next rival. China's current semiconductor industrial development is occurring at an inflection point in both the global industry, with the impending end of Moore's Law, and in Chinese-U.S. relations,

¹¹² Specifically, the ban accuses UMC, the Taiwanese joint venture partner of Fujian Jinhua, of stealing Micron intellectual property and giving it to Jinhua. *Federal Register*, "Addition to the Entity List," October 30, 2018. <https://www.federalregister.gov/documents/2018/10/30/2018-23693/addition-of-an-entity-to-the-entity-list>. See Part I of this series for a detailed discussion of this case.

¹¹³ HRM Asia, "China Talent Shortage," October 25, 2018.

¹¹⁴ Lee, "China Lures Chip Talent," September 4, 2018.

¹¹⁵ Yilun Chen, "Most China Patents Worthless," September 26, 2018.

where the semiconductor industry has become a proxy in a larger dispute. China's economic ascendance has made it an integral producer and consumer of semiconductors, raising the alarm of some who see the domestic industry's commercial advances as having positive spillovers for Chinese military development. Future research should analyze at the short term and long term tradeoffs of U.S. government actions to restrict the sale of emerging and foundational semiconductor and semiconductor-related technologies, their efficacy in slowing the development of the Chinese industry, their effect on the health and competitiveness of U.S. semiconductor firms and the extent to which these actions will result in a shift in the semiconductor global value chain to China-adjacent countries if the U.S. and China economically decouple.

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Appendix A: List of Acronyms

ATP	Assembly Test and Packaging
CFIUS	The Committee on Foreign Investment in the United States
CoCOM	Coordinating Committee for Multilateral Export Controls
DRAM	Dynamic Random Access Memory
EUV	Extreme Ultraviolet Lithography
FDI	Foreign Direct Investment
FIRRMA	Foreign Investment Risk Review Modernization Act
IC	Integrated Circuit
ITRI	Industrial Technology Research Institute
IDM	Integrated Device Manufacturer
JV	Joint Venture
MIC 2025	Made in China 2025
MITI	Medium and Long Term Plan
MNC	Multi-National Corporation
NATO	North Atlantic Treaty Organization
R&D	Research and Development
SIA	Semiconductor Industry Association
SMIC	Semiconductor Manufacturing International Corporation
SOE	State Owned Enterprise
STEM	Science, Technology, Engineering and Math
TSMC	Taiwan Semiconductor Manufacturing Corporation
UMC	United Microelectronics Corporation
VAT	Value Added Tax
YMTC	Yangtze Memory Technologies Co.

Appendix B: Current and Future Chinese Memory Chip and Foundry Services Production

Company name	Facility location	Majority ownership	Industry segment	Current WSpM*	Targeted WSpM*	Status	Process node(s) targeted	Wafer size
ACSMC	Zhuhai	Domestic	Foundry	15,000	15,000	Current	0.6 microns	150 mm
ASMC	Shanghai	Domestic	Foundry	7,000	7,000	Current	1.5 microns	120 mm
ASMC	Shanghai	Domestic	Foundry	42,000	42,000	Current	600 nm	150 mm
ASMC	Shanghai	Domestic	Foundry	29,000	29,000	Current	250 nm	200 mm
CanSemi	Guangzhou	Domestic	Foundry	0	40,000	Under Construction	180–130 nm	300 mm
CSMC	Wuxi	Domestic	Foundry	110,000	110,000	Current	500 nm	150 mm
CSMC	Wuxi	Domestic	Foundry	40,000	40,000	Current	250 nm, 130 nm	200 mm
Founder Electronics	Shenzhen	Domestic	Foundry	60,000	80,000	Current	0.6 microns	150 mm
GlobalFoundries	Chengdu	International	Foundry	10,000	85,000	On Hold	22 nm	300 mm
HHGrace	Shanghai	Domestic	Foundry	60,000	60,000	Current	90 nm	200 mm
HHGrace	Shanghai	Domestic	Foundry	60,000	60,000	Current	90 nm	200 mm
HHGrace	Shanghai	Domestic	Foundry	50,000	50,000	Current	90 nm	200 mm
Huahong Group (Shanghai Huali Microelectronics (HLMC))	Shanghai	Domestic	Foundry	35,000	35,000	Current	40 nm, 28 nm	300 mm
Huahong Group (Shanghai Huali Microelectronics (HLMC))	Shanghai	Domestic	Foundry	0	40,000	Under Construction	28 nm, 14 nm	300 mm
Huahong Group	Wuxi – Fab 7	Domestic	Foundry	0	40,000	Under Construction	90 nm, 65 nm	300 mm
Innotron (ChangXin Memory Technologies)	Hefei	Domestic	Memory (DRAM)	0	125,000	Under Construction	19 nm, 17 nm	300 mm
Intel	Dalian	International	Memory	70,000	70,000	Current	65 nm	300 mm
JHICC (Fujian Jinhua)	Jinjiang	Domestic	Memory (DRAM)	0	60,000	On Hold	22 nm	300 mm
Powerchip/ Nexchip (Hefei Jinghe)	Hefei	International	Foundry	0	40,000	Current	150 nm, 110 nm, 90 nm	300 mm
Samsung	Xi'an	International	Memory (NAND)	100,000	200,000	Current	20 nm	300 mm
SK Hynix	Wuxi	International	Memory (DRAM)	170,000	170,000	Current	22 nm	300 mm
SK Hynix	Wuxi	International	Foundry	0	100,000	Under Construction	90 nm	200 mm
SMIC	Beijing - B1	Domestic	Foundry	50,000	50,000	Current	65 nm, 40 nm	300 mm
SMIC	Beijing - B2	Domestic	Foundry	35,000	35,000	Current	28 nm	300 mm
SMIC	Shanghai - S1	Domestic	Foundry	120,000	120,000	Current	110 nm	200 mm

Table continued on next page.

Appendix B: Current and Future Chinese Memory Chip and Foundry Services Production— Continued

Company name	Facility location	Majority ownership	Industry segment	Current WSpM*	Targeted WSpM*	Status	Process node(s) targeted	Wafer size
SMIC	Shanghai - Fab 8	Domestic	Foundry	20,000	20,000	Current	40 nm, 28 nm, 14 nm	300 mm
SMIC	Shanghai - SN1	Domestic	Foundry	0	35,000	Under Construction	14 nm	300 mm
SMIC	Shenzhen	Domestic	Foundry	60,000	60,000	Current	130 nm	200 mm
SMIC	Tianjin (expansion)	Domestic	Foundry	100,000	150,000	Current (expansion)	130 nm	200 mm
TowerJazz and Tacoma Semiconductor	Nanjing	International	Foundry	0	40,000	Under Construction	TBD	200 mm
Tsinghua Unigroup	Chengdu	Domestic	Memory	0	300,000	Under Construction	TBD	300 mm
Tsinghua Unigroup	Nanjing	Domestic	Memory	0	200,000	Under Construction	TBD	300 mm
TSMC	Nanjing	International	Foundry	15,000	20,000	Current	16 nm	300 mm
UMC	Xiamen	International	Foundry	20,000	50,000	Current	40 nm, 28 nm	300 mm
UMC	Suzhou	International	Foundry	70,000	80,000	Current	0.5 micron to 110 nm	200 mm
XMC (Wuhan Xinxin)	Wuhan - Fab 12a	Domestic	Foundry	25,000	30,000	Current	32 nm	300 mm
XMC (Wuhan Xinxin)	Wuhan - Fab 12b	Domestic	Memory	0	115,000	Under Construction	40 nm	300 mm
YMTC	Wuhan	Domestic	Memory (NAND)	0	300,000	Under Construction	TBD	300 mm

* WSpM = wafer starts per month.

Source: Authors compilation; SEMI World Fab Forecast.