Available online at https://ijmras.com/

INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH AND STUDIES

ISSN: 2640 7272

Volume:06; Issue:07 (2023)

doi: 10.33826/ijmras/v06i07.2

The History and Future of China's Semiconductor Industry

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Abstract

This article is the first of two that will examine China's policies towards the semiconductor industry and the elements that will ultimately determine its success or failure. China's efforts to foster local semiconductor sector growth since 2014 have garnered significant attention from across the world. The goal of this series is to provide readers a historical perspective on the numerous efforts made by the Chinese government to promote the growth of the country's homegrown semiconductor sector, beginning in the 1950s. The first section provides a background on China's previous attempts at semiconductor industrial planning, details the current goals, and analyses their performance thus far. Part two analyses why China's strategies in the past have failed, how lessons have been applied to the present, and whether or not the current approach has a chance of succeeding.

Keywords: Semiconductors, China trade, Made in China 2025, industrial planning, global valuechains, foreign direct investment.

INTRODUCTION

All information technology relies on semiconductors as the underlying hardware. You may find semiconductors, also known as integrated circuits (ICs) or "chips," in just about any modern electronic gadget you can think of. The United States chip industry, headquartered in Silicon Valley, has been the global leader since since Jack Kilby created the first prototype integrated circuit for Texas Instruments in 1958. The production of semiconductors is notoriously difficult and requires a high level of expertise. Most large MNCs allocate over

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20% of their yearly income on R&D. Meanwhile, they're working with up to sixteen thousand vendors to coordinate the intellectual and physical assets required to manufacture chips with near-atomic feature sizes in highly automated facilities costing tens of billions of dollars and outfitted with class-one cleanrooms.

The Chinese semiconductor industry might be considered to have begun anywhere from 1956, when the first transistor was built in a state lab, to 1965, when China built its first integrated circuit. There have been four distinct eras in the evolution of China's semiconductor industry. From 1956 to 1990, the country followed a Soviet-style system of industrial organisation that prioritised independence from foreign influences. From 1990 to 2002, the Chinese semiconductor sector struggled to catch up to global leaders by forming partnerships with foreign companies and participating in joint ventures. During the years 2002–2014, a number of semiconductor companies with headquarters in China emerged with clear objectives and made significant inroads into China's burgeoning home market. China's most ambitious, well defined, and well-funded initiatives to date have been implemented between 2014 and the present, creating the best possible conditions for success.

Roadmap

This article is the first of a two-part series on the Chinese semiconductor business; it begins with an overview of the industry's structure before outlining the growth of the worldwide value chain and the sector's top corporations. The increasing demand for semiconductors in China will be the next topic of discussion as China's place in the semiconductor industry and the global electronics supply chain will be examined. The research begins with a literature review of China's industrial policies, then proceeds to an analysis of the country's semiconductor-specific industrial plans, categorising them broadly into the years 1956–1990, 1990–2002, 2002–2014, and 2014–present. Subsidies, FDI, technology transfer, joint ventures, and investment limitations are all explored in depth as they relate to China's objectives from 2014 to the present and the potential impact on the competitiveness of U.S. semiconductor firms.

In Part II of this series, we will look into two of these topics. The first is why, despite 70 years of industrial planning, China still cannot produce sophisticated semiconductors that can compete commercially with the world's market leaders. Second, how realistic are its current

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semiconductor manufacturing plans? Literature on latecomer tactics is studied, and the progress of the semiconductor industry in Taiwan, Japan, and South Korea are contrasted to China's previous and present efforts. Then, we look at the major roadblocks on China's path to prosperity, highlighting the importance that strategic finance, human capital, and export controls play. Success with China's latest plans is then discussed, showing that this version has been more thought out and is better resourced than previous attempts.

The Field of Semiconductors

In recent decades, Europe, the United States, South Korea, Japan, Taiwan, and China have all emerged as major players in the semiconductor business. Several factors, including first-mover advantages, economies of scale, brand recognition, stickiness and customer loyalty, intellectual property (IP), and expensive and fixed capital expenditures, contribute to the difficulty of breaking into the semiconductor sector. The number of companies competing in increasingly niche markets has decreased as a result of industry consolidation trends.

Costs connected with producing a cutting-edge chip have risen to the point that only the largest companies can afford them as the industry nears Moore's Law's boundaries. There has been a decline in the number of businesses able to produce cutting-edge chips as a result of the rising prices over the past 20 years, ushering in the introduction of a new business model for the sector (figure 1).

Figure 1: Operating models in the semiconductor industry, and leading firms

Integrated device manufacturer (IDM) model		
Intel, Micron, Samsung, Texas Instruments		
Fabless-foundry model		
Design (fabless)	**Manufacturing (foundries)**	**Assembly, test, and packaging (ATP)**
AMD, Broadcom, MediaTek, HiSilicon, Qualcomm	GlobalFoundries, SMIC, TSMC, UMC	Amkor, ASE, ChipPAC, JCET, J-Devices, Power-tech, SPIL

Source: Adapted from SIA, "Beyond Borders," May 2016.

The semiconductor manufacturing process consists of three stages: design, fabrication, and assembly, testing, and packaging (ATP). Companies like Intel (USA) and Samsung (Korea)

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produce semiconductors and perform all of the above processes in-house; they are known as integrated device manufacturers (IDMs). Costs associated with manufacturing semiconductors have increased, prompting the emergence of specialist firms that focus on a certain part of the manufacturing process. Pure-play foundries (contract semiconductor manufacturers without design capability) work with "fabless" companies (companies whose primary business is the design of semiconductors) to build devices for delivery to ATP companies.

The Global Value Chain for Semiconductors

A chip may be created by a company in the United States, manufactured by a foundry in Taiwan, tested in Malaysia, and then sent to China, all part of a value chain made possible by the variety of business models that exist (e.g., a smartphone). According to the Semiconductor Industry Association (SIA), the value of a chip is distributed equally between the design and production phases, with the remaining 10% contributed by ATP companies. With the exception of fabless companies Broadcom, Qualcomm, and Nvidia and TSMC, 11 of the top 15 companies in 2018 were original design manufacturers (TSMC, a foundry). In 2018, these 11 companies generated almost 53% of the entire sales in the global industry (Table 1).

Table 1: Worldwide ranking of the top-15 suppliers of semiconductors in 2018[12]

Company	Headquarters location	Operating model	2018 forecasted sales (billion)
Samsung	South Korea	IDM	$65.90
Intel	United States	IDM	$61.70
TSMC	Taiwan	Foundry	$32.20
SK Hynix	South Korea	IDM	$26.70
Micron	United States	IDM	$23.90
Broadcom	United States	Fabless	$17.80
Qualcomm	United States	Fabless	$17.00
Texas Instruments	United States	IDM	$13.90
Toshiba/Toshiba Memory	Japan	IDM	$13.30
Nvidia	United States	Fabless	$9.40
NXP	Europe	IDM	$9.30
STMicroelectronics	Europe	IDM	$8.30
Infineon	Europe	IDM	$8.10
Sony	Japan	IDM	$7.90
Western Digital / Sandisk	United States	IDM	$7.80

Source: IC Insights, "Nine Top-15 2018 Semi Suppliers Forecast to Post Double-Digit Gains," November 12, 2018.

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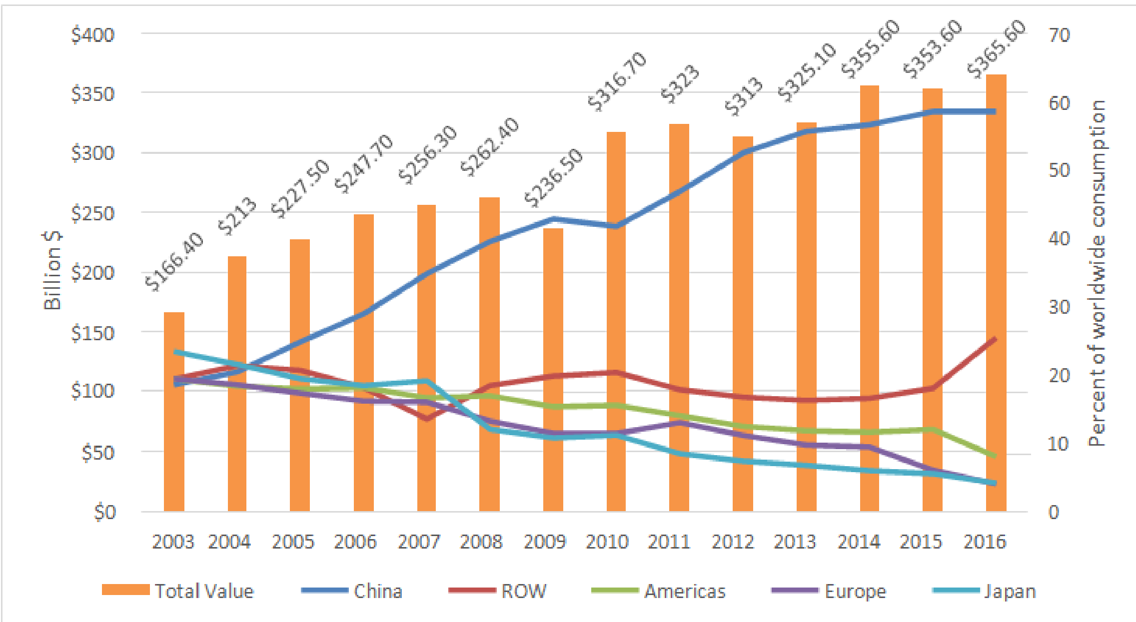
The Electronics Supply Chain in East Asia and the Growing Chinese Market

Each of the top 10 global corporations in 2018 have some sort of presence in China, from research and development centres to fabrication facilities, reflecting China's status as the largest market for semiconductors in terms of consumption. This is because there is a huge and rising need for chips used in products that China manufactures, consumes, and exports. Some sources claim that mainland China is responsible for producing 90% of the world's cellphones, 65% of laptops, and 67% of smart televisions, albeit some of these items may be manufactured in factories owned by companies with headquarters outside of China. China's vast and rising demand for chips is driven by local consumption in addition to the country's massive export assembly industry. The percentage of Chinese internet users who own a smartphone in 2013 was 43%; by 2019, that number is predicted to rise to 63%. Figure 2 indicates that every year since 2012, China's chip consumption has exceeded that of the rest of the world put together.

Figure 2: Worldwide semiconductor consumption market by region, 2003–16[15]



Source: PwC, "China's Semiconductor Market," 2017.

Despite the widespread use of semiconductors and products that use them, Chinese semiconductor manufacturers serve fewer than 5% of the global market and lag behind their

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foreign counterparts by at least two technological generations. According to some estimates, foreign businesses provide close to 90% of China's semiconductor usage.

The semiconductor business has been present in China for quite some time, even if Chinese-based companies aren't particularly well-represented in global markets. To take advantage of cheap labour costs and close proximity to this market, several of the world's major chip makers have set up back-end assembly, test, and packaging operations in China. According to the SIA, China hosted around 22% of all global back-end facilities in that year. The Related Party Trade database maintained by the United States Census Bureau provides one indicator of this supply chain relationship by showing that in 2017, nearly 60% of all semiconductors imported into the United States from China were actually from U.S.-headquartered firms' China-based subsidiaries. Since Chinese companies have such a small percentage of the global semiconductor industry, the remaining chips imported to the United States are most likely from foreign companies with a presence in China.

China's Previous Approaches to the Semiconductor Industry, 1956–2014

Previous Research on the Chinese Government's Manufacturing Strategies

Chinese industrial development strategies have evolved in response to lessons learned from analysing past plans for the country's industrial future. Assuming that technical advancements will fuel economic development, boost productivity, and raise living standards, China's strategic industrial plans aim to speed up the rate at which these things happen in certain industries. The effectiveness of these schemes, which aim to improve everything from the IT sector to the agricultural economy, has been varied. Some studies looking into the causes of this mixed success have investigated the role of systemic corruption, the misallocation of capital to state-owned enterprises, the lack of firm-level capacity to absorb FDI-related knowledge spillovers, and the fragmentation of power between national and local government, which hinders coordination of policies across the Chinese bureaucracy, as well as the ways in which state support both helps and hinders the performance of high-tech firms.

Despite these obstacles, China's strategic approach to industrial development has yielded some impressive successes. Recent research has examined the factors that have contributed to the success of specific industries, such as the impact of reverse engineering on the speedy development of domestically manufactured high-speed railways, the role of Shanghai's local

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government in fostering competitive auto industry supply chains, and the mixed effects of state policy on the growth of China's telecommunications sector.

Joint ventures' role in speeding up technology transfer, the FYPs' beneficial effects on Chinese state-owned enterprises, and the positive effects of foreign direct investment on China's manufacturing performance in terms of capacity, intensity, and quality are all topics that have been studied in depth as potential explanations for the planning successes observed. Some recent research has also explored the likely causes of the failure of China's industrial upgrading initiatives: the high complexity of high-tech production, the challenge of information dissemination, and the relevance of absorptive ability.

Studies of the early Chinese semiconductor sector in and around Shanghai began in the late 1980s, with an emphasis on the country's semiconductor-related bureaucracy and pro-business policies. Several studies were conducted in the 1990s to examine the impact of foreign direct investment (FDI) on the semiconductor sector in China and the repercussions of China's industrial growth on rival countries. Other research has zeroed in on specific semiconductor planning projects or sub-sectors of the industry, such as IC design or foundries, and examined their relative performance. In an effort to comprehend why some of China's semiconductor industrial strategies have been successful while others have failed, and how China has learnt (or failed to learn) from its efforts, several academic dissertations have presented comprehensive histories of the industry's evolution.

The first section of this research provides a summary of the previous efforts, outlines the current intentions, and examines the implementation to date of China's semiconductor industrial planning. The second part of this research delves into the reasons for the failure of earlier plans, how the lessons learnt from those failures have been integrated into the present plans, and an evaluation of the plans' likelihood of success.

Technology Development Strategies for China's Semiconductor Industry

China's strategic industrial planning in the semiconductor industry dates back to 1956 and continues now. China has released over a hundred plans for scientific and technological advancement and economic growth in the recent decade, with several of them setting domestic semiconductor industry growth as a top priority. It has been estimated that, on average, the

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Chinese central and local governments spent 100 billion RMB ($14.7 billion) in each of the five fiscal years before to 2014. Since the 1980s, the Chinese government has made it a top priority to build a semiconductor industry that can compete on the global stage and generate substantial economic value for the country. China views semiconductors as a strategic technology, and it believes that having a hand in their production will have positive effects on the economy and the military. The growth of China's semiconductor industry is divided down into several eras below, however these distinctions reflect shifts in industrial policy rather than technological progress since the analysis concentrates on the former.

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The Chinese Government's Strategy for the Semiconductor Industry, 1956-2010

From 1956 to 1990, the Chinese semiconductor industry was governed by state-led planning that prioritised homegrown creativity. The State Council of China commissioned a team of experts to draught a "Outline for Science and Technology Development, 1956-1967," which deemed advancements in semiconductor technology to be a "key priority." Almost immediately, five of China's top colleges started providing degrees in semiconductors. Several plants opened, the most noteworthy being the Huajing Group's Wuxi Factory No. 742, which began operations in 1960 and would go on to teach many of the pioneers of the embryonic Chinese industrial sector and play an important role in the development of later strategic industrial plans. China's IC sector had already surpassed that of Taiwan and South Korea by

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1965, when the Chinese Academy of Science began conducting IC research, and was "at least as advanced as Japan."

Research and development occurred in state-owned labs, while production occurred in state-owned factories; these two functions were seldom co-located during this time. Due to this divide, it was difficult to transfer technology from state labs to manufacturing facilities. Furthermore, most of the approximately 40 facilities involved in semiconductor-related production in the 1970s were making basic diodes and transistors rather than integrated circuits. In addition to making matters worse, the Cultural Revolution (1965–1975) also halted the industry's development, thereby reversing its previous successes.

Deng Xiaoping's 1978 reform and "opening" phase had a profound impact on the Chinese economy and the Chinese chip industry. With the goal of upgrading the local semiconductor sector, the State Council established a "Computer and Large Scale IC Lead Group" in the early 1980s, per the sixth FYP (1981-85). 46 In 1985, state-owned firms had spent 1.3 billion RMB importing 24 used semiconductor manufacturing lines, but only one facility (the aforementioned Wuxi Factory No. 742) reached output expectations. As a direct result of this minuscule achievement, Chinese industry leaders decided to "narrow and strengthen" state-led upgrading efforts from more than 30 organisations to only 5 "important" ones. Although these attempts were made, the industry was never able to catch up to the international leaders as a result of the accumulated defeats. In the mid-1980s, an American researcher discovered, while visiting a facility in Shanghai, that the firm was creating chips on wafers with yields as low as 20-40%, which was ten to fifteen years behind the times.

Plans for the Chinese Semiconductor Industry, 1990-2002

In an effort to speed up growth in the industrial sector, the Chinese government adopted a hybrid model in the 1990s, providing the majority of funding to a small number of large corporations so that they could form partnerships with their overseas counterparts. Late in the 1980s and into the 1990s, Nortel of Canada, Philips of the Netherlands, NEC of Japan, and ITT of Belgium all launched joint ventures. With an initial investment of 2 billion RMB and the negotiation of a joint-venture arrangement with Lucent Technologies (USA) to assist knowledge transfer, China began trying to grow Huajing (operator of Wuxi Factory No. 742)

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into a major IDM during the ninth FYP (1991-95). Project 908 took eight years to get from concept to reality, and the resulting joint venture employed antiquated manufacturing equipment and process methods to manufacture chips that trailed behind the leaders in their field.

Project 909 was launched as part of China's Ninth Five-Year Plan (1996-2000) with the goal of creating homegrown chips manufactured by a Chinese enterprise that could compete worldwide by making use of Chinese intellectual property and engineers. With the help of their relationship with NEC (Japan), the Chinese company Huahong was able to commence production on schedule (unlike Project 908) and bring DRAM chips to market. While this achievement is certainly noteworthy, it was facilitated in part by the joint venture's provisions, which allowed NEC to model the Chinese fabrication facility after an already existing factory and to staff it predominantly with Japanese experts. It's true that this choice aided in getting chips to market on time, but it also reduced knowledge spillovers, which resulted to losses of 700 million RMB in 2002 due to a worldwide DRAM market decline. Soon after, Huahong switched up its joint venture partner and business approach, but it's still going strong in 2019.

Industry Strategies for China's Semiconductor Sector, 2002-2014

China's proportion of worldwide semiconductor consumption increased from 2% in 1995 to 25% in 2005, proving that the failure of Projects 908 and 909 had no effect on the country's goals in the sector. Concurrent with this rise in consumption, China joined the World Trade Organization on December 11, 2001, making the country a more appealing location for major foreign corporations to set up shop. Unfortunately, Huahong went under in 2002, right when a rival company was getting into full swing. A Taiwanese veteran of the American firm Texas Instruments and the Taiwanese firm Worldwide Semiconductor Manufacturing Company established the Shanghai-based, foreign-owned foundry Semiconductor Manufacturing International Corporation (SMIC) in the year 2000. It began mass production in 2002 and has since risen to become one of the world's top five foundries and China's largest and most technologically sophisticated chip manufacturer. SMIC has pursued a mostly successful fast-follower strategy with the help of Chinese central and local government support, such as a five-year tax holiday (and another five-year tax break at 50 percent of standard rates), tariff

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exemptions, reduced value-added tax rates, and loans from state-owned banks. Specifically, SMIC has stayed just one to two years behind industry leaders by forming collaborations with overseas corporations and recruiting ethnic Chinese engineers (mostly returnees from the United States, Taiwan, and Singapore).

China's State Council released a National Medium- and Long-Term Science and Technological Development Plan Outline for 2006-20 (MLP) in 2005, outlining a comprehensive vision of the country's technology ecosystem and emphasising the role of semiconductors as a key component of future innovations. IDAR, or "Introducing, Digesting, Absorbing, and Re-innovating" intellectual property and technology, was advocated as a strategy of industrial catch-up in following supporting documents and policies that were inspired by the MLP. The idea behind this strategy was to foster homegrown innovation through strategic imports of foreign technology and joint efforts between the government and private sector to evaluate the acquired technology and use its insights in the creation of new goods. The present Chinese semiconductor sector promotion activities are a good example of the IDAR principle in action.

Industrial Policy in China for Semiconductors, 2014-Present

As it is, China has lofty plans to advance its homegrown semiconductor sector. These objectives are laid out in stark detail in a recent report from the U.S. Trade Representative's (USTR) Office.

China's goal is to develop a whole semiconductor manufacturing ecosystem that can operate independently from start to finish, including IC design, fabrication, packaging, testing, and the manufacture of all necessary materials and machinery.

The following three publications, all of which were published in 2014 and 2015, detail China's objectives and guiding principles for their implementation: Made in China 2025, The Guidelines to Promote a National Integrated Circuit Industry, and The Made in China 2025 Technical Area Roadmap are the three documents in question. Following an in-depth discussion of the form and substance of each plan, the subsequent discussion will focus on the plans' respective implementation to this point.

Plan and Money for the Nationwide Integrated Circuit System

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Guidelines for the Promotion of China's National Integrated Circuit Industry were issued by the Chinese Government in June of 2014. (National IC Plan). This document outlines a clear strategy that identifies "national champions" that will be supported by ample funds and bolstered by policies that promote inbound and outbound FDI. The goal of this strategy is to expedite the transfer of technology and bring China's semiconductor industry up to par with leading international competitors. Although several concepts were recycled from past plans, the paper constituted a change from other suggestions in both the degree of information it provided and the emphasis it placed on incoming and outbound foreign direct investment (FDI). Particularly noteworthy is the fact that the Guidelines for 2014 recommended the creation of a National Integrated Circuit Investment Fund (National IC Fund). This fund was charged with the responsibility of acquiring enterprises located throughout the semiconductor supply chain. It was endowed with $150 billion in funding from the federal and provincial governments.

The National IC Fund has been implementing a two-pronged strategy ever since it was first established in September of 2014. On the one hand, it provides financing for outbound FDI in the form of acquisitions of foreign enterprises. On the other hand, it offers funding to facilitate inbound foreign direct investment (FDI), including as investments in greenfields and joint ventures with businesses that are not based in China. This is done to assist in the actualization of the goals outlined in the National IC Plan. An investigation into the origins of the funding for the National IC Fund indicates that the majority of its resources originate from state-operated businesses and other types of financial organisations. According to a document submitted by Nantong Tongfu Microelectronics, which counts the Fund as an investor, the Ministry of Finance is the Fund's largest shareholder, holding a 36.74 percent share of the company. This is followed by the China Development Bank Capital Corporation, which holds a 22.29 percent share, and China Tobacco, which holds a 22.29 percent share (11.14 percent share). In addition to the establishment of the National IC Fund, a number of state, county, and municipal governments around the country have either formed their very own funds dedicated to IC, received capital contributions from the National IC Fund, or invested directly in the National IC Fund. For instance, the Beijing E-Town International Investment and Development Co. and the Shanghai Guosheng Group, both of which are investment vehicles

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owned by the municipalities of Beijing and Shanghai, respectively, have made investments in the National IC Fund. Additionally, the provincial governments of Hubei, Fujian, and Anhui have established their very own IC-related investment funds. According to estimates provided by the SIA, the National IC Fund had raised over $21 billion in financing as of the year 2017, while provincial and local IC-related funds had raised over $80 billion and are well on their way to meeting the objective of $150 billion. In 2018, many news outlets claimed that discussions were taking place between the National IC Fund and the government of China on the establishment of a second investment vehicle with an estimated value of $47 billion.

The year 2025 will see products Made in China

China's "Made in China 2025" programme was unveiled a little over a year after the country's National IC Plan, and it aims to transform a number of the country's manufacturing industries into global leaders. Next-generation information technology, controlling instruments and robotics, aerospace and aviation equipment, maritime equipment and shipbuilding, railway equipment, energy-efficient and new-energy vehicles, electrical equipment, new materials, medical devices, and agricultural machinery are the ten sectors identified, which together account for 40 percent of China's value-added manufacturing. The purpose of Made in China 2025 is to increase Chinese enterprises' market share in order to fulfil local and worldwide demand for their products by cultivating high-quality manufacturing sectors that can produce innovative products in cutting-edge facilities run by recognisable brands. To achieve this objective, a number of national and provincial funds were established to support local research and development, international technology acquisition, and the development of the infrastructure, intellectual property, and corporate identity that would be required to commercialise the end result.

Made in China 2025 reaffirmed China's commitment to cutting-edge IT by emphasising semiconductors and integrated circuits (ICs). The State Council issued the Technical Area Roadmap in October 2015, following the National IC Guidelines and Made in China 2025, with the non-binding goals of "developing the IC design industry, speeding the development of the IC manufacturing industry, upgrading the advanced packaging and testing industry, and facilitating breakthroughs in the key equipment and materials of integrated circuits."

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According to the Roadmap, by 2020 China will have a well-developed local supply chain of equipment, material, and ATP service providers, allowing it to be just one to two generations behind the leaders in semiconductor design and production. The strategy states that by 2030, "the key segments of the IC industry... attain advanced worldwide standards." To minimise its reliance on memory chips from the United States, China's 13th FYP (2016-20) was issued in 2015, and it was much more detailed, placing an emphasis on the production of DRAM chips (similar to Huahong's attempt with Project 909).

Assistance Programs for Realizing the Strategy

China's current semiconductor industry ambitions are represented by the National IC Plan and Made in China 2025. Together, these plans advocate for a "fast-follower" strategy in China's semiconductor sector. Since leading companies can no longer win the innovation race by merely producing faster and more powerful processors, this situation allows the industry to leapfrog ahead many generations in order to catch up with foreign competitors.

Subsidies are a crucial part of China's plan for its semiconductor sector, and this support comes in the form of regional, provincial, and national funds (such as the National IC fund), investment vehicles, and regulations that stimulate investment in the industry (such as tax cuts). There are two things to keep in mind while trying to fathom the magnitude of the Chinese investment in the semiconductor sector. To begin, the National IC Fund is the second largest of the eleven funds the U.S. Chamber of Commerce has designated as focusing on Made in China 2025 businesses. The largest is the more broad Special Constructive Fund. Second, substantial investment is needed for the semiconductor sector to progress. Developing a complex microprocessor can cost well over a billion dollars. However, the cost of constructing a new manufacturing facility that can produce such a sophisticated chip design is substantial. TSMC's newest facility in Taiwan, for instance, is estimated to cost $16 billion when it is finished and will produce some of the most sophisticated chips in the world.

In order to emphasise the priority it placed on developing indigenous skills in this industry, the Chinese government established a fund specifically for the purpose of supporting it, and provided it with enough money to construct over 20 state-of-the-art production facilities. Direct

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methods of support, such as eliminating corporate income taxes for semiconductor businesses, go beyond the creation of funds.

Indirect Investment From Overseas Sources

Outbound Chinese FDI in the semiconductor sector has skyrocketed thanks to an injection of money from national and subnational funds. U.S. Trade Representative's latest report defines this growth in precise words.

Chinese companies and investors, often backed by state capital, have made a series of acquisitions since 2014, when the government issued the Guidelines, in an effort to make technological breakthroughs, close the gap with advanced countries, foster domestic innovation clusters, and lessen China's reliance on foreign-made integrated circuits (ICs).

According to the Rhodium Group's findings, Chinese firms only engaged in six M&A deals with U.S.-based semiconductor companies before 2014, for a total of $213.8 million. By 2016, the number of announced M&As had increased to 34 U.S. firms, and the total value of completed transactions had reached $8.1 billion, all thanks to the availability of newly accessible capital. Towards $11 billion, according to a study published at the year's end (see appendix B for a complete list).

Furthermore, huge quantities of Chinese venture capital money have been invested in the U.S. semiconductor business. For example, Danhua Capital (now known as Digital Horizon Capital) has invested in 113 U.S. companies operating in industries that the Chinese government has flagged as "strategic priorities," including Canyon Bridge Partners' bid for Lattice Semiconductor (which was nixed by the U.S. government on national security grounds83). Companies at all stages of the semiconductor supply chain have been funded, from those making and owning the necessary equipment and intellectual property to those responsible for final assembly, testing, and packaging. Companies specialising in memory chips, microelectronic mechanical devices (MEMS), and chips constructed from materials other than silicon have all been acquired in this wave of mergers and acquisitions (M&A).

While the United States has been a major target, Chinese investment outside the country has gone into a variety of sectors. There has been a comparable uptick in mergers and acquisitions by newly acquisitive Chinese investors in other nations with sophisticated semiconductor

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businesses. In order to complete its purchase of Freescale Semiconductor, NXP Semiconductors (The Netherlands) was required by the U.S. Federal Trade Commission to sell up its Radio Frequency (RF) business unit. Two investors with links to the Chinese government, Jianguang Asset Management and Wise Road Capital, purchased the RF business unit after it was sold. 86 Earlier this year, the China Development Bank and the National IC Fund joined forces with local and central governments and state-owned firms to acquire STATS ChipPAC, a Singaporean packaging and testing firm.

Concerns that some of Germany's "crown jewels" may be sold to China prompted increased scrutiny of Chinese acquisitions in 2016. At the time, Chinese firms were showing a growing interest in the country's sophisticated manufacturing sector. German officials are worried about Chinese investment after the robotics business Kuka was purchased and rumours spread that Osram Licht, a lighting and semiconductor manufacturer located in Munich, was up for sale to the Chinese. After a big order cancellation from a Chinese customer, Aixtron, a German maker of equipment used in the semiconductor production process, saw its stock price drop while it considered a buyout approach from a second Chinese investor. The acquisition was blocked by the German authorities and the U.S. Committee on Foreign Investment after it was discovered that Aixtron's potential investor had undisclosed relations with the business that cancelled their purchase. Subsequent investigation of the Chinese client and the potential investor uncovered connections to the Chinese government.

JOINT VENTURE AND TECHNOLOGY TRANSFER REQUIREMENTS FOR PLAN IMPLEMENTATION

Constrained Investments: Partnerships

International semiconductor firms have been pushed to set up shop in China in order to obtain access to the local market, despite the fact that doing so would be in their best interests due to China's low labour costs and rapidly expanding middle class. The Organization for Economic Co-operation and Development (OECD) reports that, among the G20 countries, China is the most restrictive when it comes to accepting foreign direct investment (FDI). In order to break into the Chinese market, American tech companies are often advised to build a partnership with a local Chinese company, as stated by the Information Technology and Innovation

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Foundation. According to a recent report by the U.S. Trade Representative, Chinese officials may condition investment approval based on:

• Foreign equity caps and joint-venture requirements

• The maintenance of a case-by-case administrative approval system for a wide range of investments

• A requirement that a foreign enterprise transfer technology

• A requirement that a foreign enterprise conduct R&D in China

• A requirement that a foreign enterprise transfer technology

U.S. semiconductor companies tolerate these limits while working to alleviate them because of China's centrality to the global electronics value chain and the magnitude of the Chinese market. So, between 2014 and 2018, the majority of the top U.S. semiconductor manufacturers set up either a greenfield FDI or a joint venture in China. Since 2014, when the National IC Plan was established, a number of the most prominent U.S. semiconductor companies have made announcements of incoming foreign direct investment (FDI), which are summarised in Table 2.

Multinational companies (MNCs) have been encouraged to launch new initiatives and deepen existing relationships as a result of national, provincial, and municipal funds made available under the National IC Plan and Made in China 2025. The three largest foundries in the world—GlobalFoundries (United States), TSMC (Taiwan), and UMC (United Microelectronics Corporation)—have announced plans to establish new fabrication facilities in China. These companies join industry leaders Intel (United States), SK Hynix (South Korea), and Samsung (South Korea), all of which are taking advantage of subsidised loans from the Chinese government to expand existing operations in China.

Despite these massive expenditures, top semiconductor companies have not decided to establish their cutting-edge operations in the nation. In reality, while companies like Intel, SK Hynix, and Samsung have sizable facilities in China to service the growing demand for memory chips in the nation, the bulk of their cutting-edge manufacturing continues to take place at home. Reasons for this choice include the absence of tariffs on international commerce in semiconductors. As a result, providing cutting-edge items to the Chinese market from abroad facilities incurs minimal additional expenses, provided that companies maintain efficient

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supply chains. In addition, as we'll see in the following section, big multinational corporations are apprehensive about high-value manufacturing in China due to theft concerns.

Table 2: Select U.S. semiconductor firms' foreign direct investments in China, 2014–18

Announced date	Non-Chinese company	Chinese company
Jan-14	IBM	Suzhou PowerCore
Mar-14	IBM	Teamsun
Sep-14	Intel	Tsinghua Unigroup
Nov-14	Texas Instruments	Existing Texas Instruments facility expansion
Dec-14	Micron	PowerTech (Taiwan)
Jan-15	Qualcomm-IMEC	SMIC, Huawei
May-15	Hewlett-Packard	Tsinghua Holdings (Unisplendour)
Jun-15	Broadcom	H3C Technologies Co.
Sep-15	Cisco Systems	Inspur Group
Dec-15	Qualcomm	SJ Semi (SMIC & Jiangsu Changjiang Electronics Technology JV)
Jan-16	Qualcomm*	Guizhou Province (Huaxintong)
Jan-16	Intel	Tsinghua University and Montage Technology Global Holdings
Apr-16	AMD	Tianjin Haiguang Advanced Technology Investment Company
May-16	Brocade	Guizhou High-Tech Industrial Investment Group
May-16	Dell	Guizhou YottaCloud Technologies
May-16	VMWare	Sugon Information
Sep-16	Western Digital	Tsinghua Unigroup (Unisplendour)
Feb-17	GlobalFoundries	Chengdu Municipality
Mar-17	IBM	Wanda Internet Technology Group
Jul-17	Nvidia	Baidu
Feb-18	Intel	Tsinghua Unigroup (Spreadtrum & RDA)
May-18	Qualcomm	Datang Telecom Technology Co.

Note: * = Since dissolved.

Source: Compiled by author.

Prerequisites for Technology Transfer

It is not a new phenomenon that China's present strategic plans for the semiconductor sector include implicit and explicit criteria that force foreign semiconductor companies to create joint ventures with their Chinese counterparts and surrender technology in exchange for market access. The delicate nature of the technology transfer requirements95 put on American semiconductor firms is why they are rarely discussed openly. The U.S.-China Business Council conducted a study in 2017 and found that 19% of responding firms had received at least one request to transfer technology to China in the previous year, with 30% of those requests coming from a central government entity. According to a 2017 survey of the American IC design and

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manufacturing sector conducted by the Bureau of Industry and Security of the United States Department of Commerce, 25 American firms reported needing to enter into joint ventures with Chinese entities and/or transfer intellectual property in order to maintain market access. The replying businesses were not little fry by any stretch of the imagination, either; together they accounted for $25 billion in revenue and produced 26% of all ICs sold in the United States. Micron, headquartered in Idaho and holding a 20-25% share of the market for dynamic random access memory chips, is an excellent example of the difficulties encountered by U.S. semiconductor businesses operating in China. After Micron rejected a $23 billion buyout approach from China's Tsinghua Unigroup in 2015, the Chinese company went on to steal the CEO of Micron's Taiwan-based joint venture. Soon after, several employees of Micron's Taiwan-based joint venture were charged by Taiwanese prosecutors with stealing Micron IP (worth $8.75 billion) and sharing it with Tsinghua Unigroup and Fujian Jinhua Integrated Circuit Company (owned by the Chinese province of Fujian) to aid in their own development of DRAM. Fujian Jinhua countersued Micron for intellectual property theft by claiming that Micron's Chinese affiliates had violated patents that were itself based on stolen Micron technology. Earlier this year, in July 2018, a Chinese court sided with the Chinese company. At the same time that this case is being heard, the regulatory authorities in China are conducting an antitrust investigation into price fixing in the memory chip industry, in which Micron is a suspect. Qualcomm, the largest fabless semiconductor maker in the United States, was penalised $975 million by the same regulatory body, the National Development and Reform Commission, for overcharging for patent fees.

CONCLUSION

China's efforts to develop a local semiconductor sector that can compete on the global market have had mixed results so far. With rising domestic demand and a pivotal position in the global electronics value chain, China is increasingly dependent on imports of semiconductors, which has prompted the government to prepare for the development of a domestic sector. The most recent efforts by the Chinese government to achieve this aim are the 2014 Guidelines to Promote a National Integrated Circuit Industry and the Made in China 2025 initiative, both of which were launched in 2015. Looking back at the development of China's semiconductor

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industry reveals the continuous conflict between central planning and the sector's capacity to compete on a global scale. Despite this friction, China's current plans have a higher probability of success than earlier iterations since they include lessons learnt from the past.

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