Micron Ex. 2007, p. 1
YMTC v. Micron
IPR2025-00500

status in these technological frontier areas. For example, the MST chose Baidu, Alibaba, Tencent, iFlytek and SenseTime as the first group of companies cooperating with the government on China's national open AI innovation platform (Chen and Liu 2017). Huawei, JD.com, Xiaomi and other private companies and SOEs were chosen as the second group of companies for the same purpose in 2019 (Yang 2019). In June 2020, China's power giant SOE State Grid announced the signing of a cooperation agreement with private giants Huawei, Alibaba, Tencent and Baidu for building a new type of digital infrastructure in the energy sector (Xinhua 2020).

At the same time, the government also made huge investments and created policies to encourage its government institutions and SOEs to make breakthroughs in what it defined as core technologies, such as semiconductors, basic software, operating systems and high-end computer numerical control machine tools. The problems existing in China's research system and techno-industrial development, however, still hinder the government-sponsored digitalization in these frontier areas.

Can China achieve its goals of becoming a real technological powerhouse to sustain its economic growth and a "great national rejuvenation"? It depends on whether China can overcome its weakness and shortcomings in the rigid S&T research system, which is deeply rooted in its political structure, as well as the problematic techno-industry connection to release the power of China's potential capacity in S&T innovation. It may also depend on whether China can continue to support and further encourage confidence in the country's private companies to fulfill its goals of developing into a technological powerhouse. China was also increasingly constrained by the growing "splinternet"[28] on the global stage. China's high-tech and internet companies face more geopolitical hinderance from plans such as the Clean Network proposed by Secretary of State Mike Pompeo under the Trump administration. The rapid growth of Huawei and ByteDance (TikTok) has been delayed by the consequences brought by the splinternet effect.

28 Splinternet refers to a characterization of the global internet that used to be free and open as splintering and dividing due to political agenda, technology, commerce and various other factors — for example, a bifurcation into a Chinese-led internet and a non-Chinese internet led by the United States. It is also called cyber or internet balkanization.

In the era of the digital economy, chips are crucial to all cutting-edge, high-tech devices, such as next-generation mobile networks, AI, supercomputers and self-driving cars. The capacity for chip design and manufacturing represent, to some degree, a country's comprehensive strength in S&T and determine its industry and military capacity. The following case study on China's semiconductor industry illustrates the country's techno-industrial development in recent decades and discusses the implications of the answers to the question above.

Case Study: From Paper Tiger to Real Tiger? The Development of China's Semiconductor Industry

A Short History of China's Semiconductor Industry (1960–2014)

1960–1978

China began to develop its semiconductor industry around 1960, at about the same time as Japan started its semiconductor industry. During 1960–1978, although the state-supported indigenous R&D and industry model helped establish China's semiconductor industry and made a few technological achievements, low-level industrialization during the chaotic period of the Cultural Revolution meant China's semiconductor sector fell further behind that of the United States and Japan. The total products made by more than 600 Chinese semiconductor factories only accounted for one-tenth of the products made by one large Japanese factory in one month (Li 2014).

1978–2000

During the first two decades of reform and opening up (1978–2000), the gap between the Chinese semiconductor industry and the advanced US and Japanese semiconductor sector became even wider. China's semiconductor sector even fell behind newly risen semiconductor industries in Taiwan and South Korea. Market-oriented reform and the opening-up policy allowed high-quality and cheap imported chips to dominate the domestic market supply, and Chinese semiconductor enterprises suffered great losses because of low profits and loss of market share. A large proportion of production lines relying on imported semiconductors were operating at a low technical level due to technology blocks by Western countries and fell into a vicious circle: technology acquisition, building a production line, manufacturing, falling behind and importing again.

Top policy makers during this period were aware of the backwardness in China's semiconductor industry and were determined to make changes. President Jiang Zemin was shocked by the rapid growth of South Korea's semiconductor industry and expressed the need to "develop China's semiconductor industry at all costs" after visiting Samsung's semiconductor factory at the end of 1995 (Jia and Song 2020). Project 908 and Project 909 were the main projects implemented after Chinese leaders announced their resolution to develop China's semiconductor industry. Project 908 was centred on Wuxi Hua Jing's foundry production line and supplemented with a number of firms and research institutions and universities on fabless design. It took seven years before the factory was established. The bureaucratic process of approving and building the production line killed the project as the slow process made its semiconductor products obsolete when it began to produce. Taking the lessons learned from Project 908, nationwide resources were mobilized to support Project 909 and all bureaucratic barriers and red tape policies were streamlined. It took only two years to establish the flagship semiconductor company Shanghai Hua Hong, which began to profit in the following years. The nationwide support did not last for too long, however — Hua Hong suffered huge losses as a result of the global recession's impact on the semiconductor sector around 2000 and lost its lustre, and as well as national support, after that.[29]

Although top leaders gave decent attention to developing the semiconductor industry and as well as related policy and financial support, China's semiconductor sector failed to narrow the gap with its foreign counterparts during the period. The government-dominated model of investment for the semiconductor industry revealed some fatal problems that restricted China's catch-up strategy in the semiconductor sector. The rigid bureaucratic system would kill the state-sponsored projects, as Project 908 showed. Even with a huge amount of investment and privileged policies from the top to clear the bureaucratic red tape, these state-sponsored projects could fail due to fierce global competition and fast-evolving semiconductor technology, as Project 909 indicated.

The policy and financial support from the government were not consistent, demonstrating that the policy makers did not fully understand the very significance of semiconductors to a country's technological power and economic growth in the future, nor did they comprehend the features of the semiconductor industry in terms of its high investment and risk and long-term accumulation of technologies and talents. It was reasonable for the leaders to think and act in this way as the development of the semiconductor industry was not a "life or death" issue at the time. China's economy continued its rapid growth and the imported semiconductor products could meet the domestic demand. In addition, technology backwardness and lack of talent constricted China's capacity for technology acquisition, adaptation and innovation. Chinese technicians and workers could hardly understand the advanced semiconductor technologies, let alone carry out adaptation and innovation based on them.

2000–2014

The arrival of the internet era and rapid growth of information technology in the late 1990s refreshed Chinese elites and leaders' realization of the significance of the semiconductor industry. In 2000, the State Council issued the Circular of Several Policies on Encouraging the Development of Software and Integrated Circuit Industries (State Council 2000). Ushering in policies on investment and financing, taxation, industry and technology, export and so on to promote the IC industry, the circular signalled a wave of chip enterprises in the first few years of the 2000s.

Encouraged by the Chinese government's policies, both state-owned and private IC enterprises were established in great numbers and some of them survived and developed into flagship companies in China's IC sector. For example, Semiconductor Manufacturing International Corporation (SMIC) in IC foundry and HiSilicon and Spreadtrum

29 Project 909's flagship enterprise, Hua Hong, barely survived the global semiconductor sector recession around 2000 but has developed into a heavyweight player in China's current foundry arena.

Communications Inc. in fabless design, as well as other top Chinese IC enterprises were established during the period. Overseas returnee talents in semiconductors became the leading entrepreneurs in China's emerging chip companies.

However, even with the rapid growth of Chinese IC in the 2000s, the industry, facing cutthroat global competition, again failed to catch up. The growing company SMIC lost a case of IP theft and patent infringement against Taiwan Semiconductor Manufacturing Company (TSMC) during the period, symbolizing a heavy blow to the fledgling Chinese IC industry, which has experienced a mediocre period since then. The technological gap between SMIC and TSMC in chip manufacturing and between China's IC industry and the world's advanced IC level has been even wider. China's IC industry has stalled in the making of low-end chips with a low profit, and the market for high-end chips relied heavily on foreign supply.

The Chinese government sponsored a series of projects focused on achieving technological breakthroughs in the field of CPU chips, such as Arca CPU, Loongson CPU and MPRC CPU under the support from national projects such as the 863 Program,[30] the 973 Program and the "Core, High and Basic" (*HeGaoJi* in Chinese) Project.[31] These state-sponsored catch-up projects, featuring a quick-success and campaign-style strategy, basically failed, with a few exceptions, including the Sunway CPU for the supercomputer Sunway TaihuLight, which was the fastest supercomputer in the world from June 2016 to June 2018.

Arca CPU had once secured state support and government procurement from the Beijing municipal government but eventually failed to pass the basic test for being a commercially viable product (Fuller 2016, 167). Arca developed its Arca-1 CPU and related hardware and used the Linux operating system to evade Intel's CPU-centred ecosystem[32] and Windows' operating system. However, Arca-based PCs and network computers (NCs) relied on the Linux system and related software, which were incompatible with dominant Windows software products such as Office. Many government agencies and institutions boycotted or bluntly refused to use NCs that installed the Linux system and were supported by Arca CPU because of the awful user experiences. In the end, the lousy user experience led to Arca-based PCs and NCs being abandoned in the market, which signalled the failure of the quick-success strategy in building China's own independent Arca CPU-based ecosystem.

The notorious Hanxin digital signal processing (DSP) microchip scandal[33] in 2006 destroyed the reputation of indigenous CPU chips and the IC sector in China. It is a typical case that revealed some serious problems existing in China's bureaucracy-standard S&T research system, such as lax standards for assessing the authenticity and originality of research findings and widespread academic cheating and fake findings. This explains, in a way, why the catch-up strategy for quick success would not work in the IC field. Impacted by the Hanxin scandal, the indigenous innovation in China's IC sector was questioned and many projects were suspended. The government's financial and policy support was severely reduced accordingly.

To sum up, China's strategy during 2000–2014 changed to encourage both private companies and SOEs to invest in the IC sector instead of state direct investment for developing flagship IC enterprises. This change of strategy had both positive and negative repercussions. On the one hand, the wave of enterprise establishment in the first half of the 2000s laid the foundation for China building its IC industrial chain. Many of them have become pillar enterprises in China's IC industry since then. On the other hand, some observers argued that a nationally coordinated, consistent strategy is still crucial for cultivating China's flagship enterprises and accomplishing

30 It added a special project for very large-scale integration design under the 10th Five-Year Plan in 2001.

31 The development of "core electronic devices, high-end general-purpose chips and basic software" was listed as the top one in the 13 major projects under the National S&T Program in the MLP and also the number one priority in China's definition for strategic emerging industry for the 12th Five-Year Plan (2011–2016). It was known as the "Core, High and Basic" Project for short.

32 Ecosystem in the ICT sector means technological platform and supply chain (industrial chain). The global IT industry is basically built on two ecosystems: Wintel (Windows operating system plus Intel CPU) and AA (ARM CPU and Android operating system).

33 Hanxin 1, the so-called first DSP chip wholly developed in China, turned out to be a totally fake one. It is a Motorola DSP 56800 chip made by Freescale, the semiconductor sector of Motorola, with the original identifications and logo of "Motorola" sanded away and replaced with "汉芯一号" (Hanxin 1 in Chinese).

key progress in IC technology and innovation. The fiscal support from the government, such as the special major projects 863, 973, and "Core, High, and Basic," is not providing enough consistent financial support for China's IC sector to catch up.[34] This, once again, demonstrated a lack of realization of the importance of the IC sector.

The most important reason for the failure to make breakthroughs in the IC industry during 2000–2014, however, lies in a disconnect or a conflict between government support and the market-oriented approach. Given the features of the IC industry, such as being highly competitive, the high costs of trial and error, and rapidly evolving technologies, an approach that separated the forces of government and the market weakened both. The clash is deeply rooted in China's state-controlled model of technological development, in which the government-sponsored projects could not produce commercially viable products while also failing to provide the needed financial and policy support to encourage private companies to develop and catch up.

Latest Developments since the Introduction of the Fund in 2014

The year 2014 represented a new era for China's IC industry. The establishment of the National Integrated Circuit Industry Investment Fund (the fund) and the release of the Outline of the Program for National Integrated Circuit Industry Development (the outline) by the State Council in that year marked a great leap forward in the government's financial and political support for China's IC industry. The establishment of the fund showed Xi's endorsement for the elite's idea of strong and consistent government support for latecomers to pursue a catch-up strategy in key technological areas and industries.

Organized and supervised by the MIIT and the MOF, a fund of 138.7 billion yuan was finally set up in 2014 with multiple government and SOE sponsors, including the MOF, China Development Bank Capital (CDB Capital), China National Tobacco Corporation (CNTC), Beijing E-Town International Investment & Development Co., Ltd. (E-Town Capital), China Mobile and Unigroup (Zhang 2014; Fan 2018). Phase two of the fund got under way in 2018 when phase one finished its investment. It had an even bigger goal of fundraising a total of 200 billion yuan. The MOF and CDB Capital remained as the top two shareholders, with further capital input of 22.5 billion yuan from the MOF (11.02 percent) and 22 billion yuan from CDB Capital (10.78 percent). CNTC and four other SOEs invested 15 billion yuan each and more private companies and local governments from Yangzi River economic zones purchased the shares (*China Securities Journal* 2019).

A crucial question needed to be answered when China's support for the IC industry reached a new level in 2014: does China need to build the whole chip industrial chain, which includes design, fabrication, packaging and testing, equipment, materials, and core IP, for the sake of industrial security and national security? Some experts indicated that no country could develop the whole IC industrial chain, and China should hold an open-minded attitude and follow the route of global cooperation for its IC sector growth (Li 2019). This meant China focused on certain links of the IC industry, such as design and packaging and testing, and relied on imported chips manufactured overseas.

The outline made it clear that China was aiming to achieve an advanced level at each link of the whole IC industrial chain (MIIT 2014a). The fund investment behaviour followed the same spirit. China realized that in the era of the internet and information technology revolution, the IC industry has strategic significance for both economic growth and national security. Theoretically, a lack of any core technologies in IC design, fabrication, packaging and testing, equipment and materials, and IP core could risk China's industrial and national security. This way of thinking is getting more and more attention under the circumstances of the tech war and decoupling that have evolved between China and the United States since 2018.

The fund greatly boosted the financing for China's IC sector, and China started a serious restructuring to advance the whole IC supply chain, but with an emphasis on fabrication. The 138.7 billion yuan raised in the fund's phase one leveraged financing amounting to 500 billion yuan by 2018 (Li and Lai 2019). Through equity investment, the fund put most of its capital in IC fabrication, in particular, memory chips manufacturing. The promised investment in fabrication, design, packaging and testing, equipment and materials account, respectively, for 63 percent, 20 percent, 10 percent and seven percent of the total investment by the fund (*People's Posts and Telecommunications News* 2017).[35] Seventy percent of the fund investment went to the top three enterprises in each category and sub-category to make

34 The national IC fund approved in 2014 demonstrated, in their eyes, a substantive support from government for the IC sector.

35 According to the statistics by the Institute of China Merchants Bank report, these number were 67 percent, 17 percent, 10 percent and six percent by the end of 2018 when the fund's phase one finished (Institute of China Merchants Bank 2019).

these companies stronger and better, with 5–10 billion yuan going to each one: Yangtze Memory Technologies Co., Ltd. (YMTC), SMIC and Hua Hong Semiconductor Limited in foundry; Unisoc and Sanechips Technology Co., Ltd. (Sanechips) in fabless; Jiansu Changjiang Electronics Tech Co. (JCET), Tongfu Microelectronics Co., Ltd. and Tianshui Huatian Technology Co., Ltd. in packaging and testing; Advanced Micro-Fabrication Equipment Inc. (AMEC) and NAURA Technology Group Co. Ltd. (NAURA) in equipment; and National Silicon Industry Group and Anji Micro Shanghai Co., Ltd. in materials (ibid.).

Focusing mainly on equity and fund investment in a market-oriented way, the fund changed the way the Chinese government directly subsidized the IC sector. The fund boosted a new round of investment in China's IC sector. The domestic sale of IC products kept an average rate of increase of 20 percent over 2014–2018, the period of operation for the fund's phase one (China Semiconductor Industry Association 2018, 2019). Another area the fund focused on is overseas M&A to acquire high-end technologies. A few successful acquisitions helped speed up China's rise in IC design and packaging. For example, under the support from the fund, Unigroup acquired Spreadtrum Communications and RDA Microelectronics, and JCET acquired STATS ChipPAC, the world's fourth-largest IC packaging firm, located in Singapore.

The thing is, however, that most of the technologies invested in and purchased are generations behind the international advanced ones, especially in IC foundry. For example, the outline set the goal of realizing mass production of 32/28 nm (nanometre) chips by 2015 and 16/14 nm by 2020 in foundry, which is still two–three generations behind the TSMC. In the field of memory chips, the fund invested in the YMTC's 64-layer 3D NAND, which is generations behind the international advanced 128-layer chip produced by Samsung and Micron. As for the approach of M&A for technology, the failed attempt to purchase Micron in 2015 symbolized the end of this investment strategy by the fund.

China's IC industry has long been restricted by the lack of huge investment, the low level of technology and the reliance on foreign core technologies. It is understandable that the fund supported companies building IC factories or improving technological capacity through M&A for a quick rise. However, it seems incomprehensible that the fund did not specify any investment in indigenous innovation and long-term R&D, which are fundamental issues in the IC industry.

The primary reason for the lack of investment is the impact of the bureaucracy standard, under which the same short-cut approach for quick success still dominated China's IC development, and most of the fund investment went to low-end IC fabrication, packaging and testing for domestic market supply to make quick money. Although it was announced that it would follow market rules for equity investment, the fund is still dominated by the government agencies in charge (the MIIT and the IC leading group). The chairman of the board, Wang Zhanfu, is the director of the finance department of the MIIT, and the president of the fund, Ding Wenwu, is the director of the electronic information department of the MIIT. Possible accomplishments caused by the R&D expenditure and technological innovation would take 10–20 years to achieve and accumulate; no government officials in charge are willing to invest in fundamental R&D and technological innovation as the results would not be seen in the short term.

The bureaucracy standard created the long-standing institutional restrictions that obstructed the fund from following market rules for investment. In general, the institutional restrictions mean the fund must follow officials' instructions and intentions to choose projects for investment. As a government investment, the fund is supposed to have a similar rigid standard for assessment of "maintaining and adding value of state-owned assets," under which the fund would not tolerate loss and failure of its investment. In the approval process for the capital investment by the fund, financial indicators such as profitability and market value of a company have significant sway. This explains why the fund invested in top "dragon head"[36] enterprises in the fields of foundry packaging and fabless design, but provided far less capital for R&D, in order to assure that visible profit and solid accomplishment can be achieved in each year the fund is operating.

That being said, the fund did provide some promising prospects for China's IC industry. A catch-up strategy in 5G chips, AI chips, the IoT, autonomous vehicles and smart cities will be the focus of the fund's phase two, in particular, AI chips and the IoT. In the field of AI chips,

36 "Dragon head" is a term that is literally translated from Chinese. It means flagship enterprises or national champions enterprises.

which consists of GPUs, field-programmable gate arrays (FPGAs) and application-specific ICs, many Chinese start-up companies have been at the forefront in terminal chips, and Cambricon Technologies has developed into one of China's most valuable AI chip start-ups and the flagship company in China's AI chip industry. The fund's phase two could help accelerate the promising trend in the development of China's AI sector.

The Status of China's Semiconductor Sector

The outline gave an official assessment of China's IC sector in 2014: in general, there is still a big gap between China's IC industry and advanced countries, although rapid growth of the IC industry in China has been achieved in the past decade (MIIT 2014b). In line with the outline, the MIIT emphasized in June 2014 that the IC sector was too weak and small to support China's economic growth and meet the demand of state information security and national security (MIIT 2014a).

In its 2014 review of the IC sector, the MIIT admitted that the technology of IC fabrication in China lags at least one–two generations behind the international advanced level, IC design was in its fledging stage with a single product structure, and IC packaging and testing still has a wide technical gap with the prominent international enterprises. Most importantly, R&D intensity (the ratio of expenditures on R&D by a firm to the firm's sales) among China's IC flagship companies, such as SMIC, falls far behind the international IC tycoons, such as Qualcomm, TSMC, Intel and SK Hynix. The MIIT warned that lack of investment and low R&D expenditures could further widen the technical gap between China's IC companies and prestigious international enterprises (MIIT 2015).

Compared to the relatively moderate tone in the official documents, experts from the IC sector were more blunt about China's backwardness and weakness in this field. In their view, China still falls behind in terms of technology in IC manufacturing, storage and packaging, five years after the 2014 outline was released. In particular, IC manufacturing still has a huge technical gap, equal to two–three generations behind. Most high-end IC design is still controlled by foreign enterprises and most domestic companies can only supply mid-to-low-end design (Zu 2018). The only exceptional case is Huawei's impressive achievements in 5G chips, including base station and baseband chips and smartphone SoCs (system on a chip) (see Table 9 in the appendix for market percentage of Chinese chips). In general, domestic IC enterprises can supply low-end products while high-end chips rely heavily on imports, with the value of IC products having become the single largest imported item since 2015 and the value of IC imports reaching as high as US$312 billion in 2018 (China Semiconductor Industry Association 2019) and US$305 billion in 2019 (China Semiconductor Industry Association 2020). The net import of IC products reached as high as US$227 billion in 2018, rising from $193 billion in 2017, and dropped to $204 billion in 2019 (China Semiconductor Industry Association 2018, 2019, 2020).

Specifically, the landscape of China's IC sector after two decades of development looks like this: Seen from the supply chain, Chinese enterprises have risen rapidly, and a few fabless enterprises such as Hisilicon and Unisoc have emerged into the advanced level in the global field of IC design. But Hisilicon is not supplying the external market and Unisoc is mainly designing low-end chips. Qualcomm and other foreign companies hold the high-end chips market. In the field of fabrication, there is still a two-generation technical gap (Ernst 2020). China's champion foundry company SMIC can manufacture 14 nm chips but lacks capacity for mass production, while TSMC has capacity for mass production of 7 nm and 5 nm chips. Chinese companies have achieved the advanced level in packaging and testing, which has a lower technical threshold. JCET and Shanghai Micro Electronics Equipment Co., Ltd. are two frontrunners in advanced packaging. In the area of IC equipment, China falls far behind in almost every link, such as lithography, etching, physical and chemical vapour deposition (PVD/CVD), thermal processors, ion implantation and chemical mechanical planarization. ASML monopolizes the field of lithography. Together with four other international companies, Applied Materials, Tokyo Electron Limited, Lam Research and KLA Corporation, the five top companies account for 80 percent of IC equipment fabrication and material engineering (China Securities 2020). Chinese flagship companies in this field, such as AMEC and NAURA, currently focus on low-end IC fabrication equipment, including etchers and PVD/CVD.

Looking at the categorized IC products, global integrated device manufacturer (IDM) companies dominate in the memory chip market, with

Samsung, SK Hynix and Micron accounting for 95 percent of the dynamic random-access memory (DRAM) market (Huang 2018) and Samsung, Toshiba, Micron, West Data, SK Hynix and Intel controlling 99 percent of the global NAND market (Roos 2017; Dongguan Securities 2020). There is almost no market space for Chinese enterprises. Wuhan Xinxin Semiconductor Manufacturing Co., Ltd. was incorporated into YMTC, a memory giant, with a huge investment of $24 billion by the fund and Unigroup in 2016 (Zheng 2017; Kim 2019).[37] YMTC is China's greatest hope in the memory market but its technological level is still falling behind. The newly established (in 2016) Jiangsu Advanced Memory Semiconductor Co., Ltd. focused on phase-change memory technology. In the area of microprocessors, including PC CPU, mobile phone SoC and other mobile terminal microprocessors and server chips, Hisilicon and Unisoc have stepped into the global advanced level, but Intel monopolizes PC CPUs and other top companies, such as Qualcomm, Broadcom, Apple, Samsung and Media Tek, dominate the mobile terminal microprocessors. In the area of analog IC, Chinese companies fall far behind. Chinese flagship enterprise SG Micro, with a smaller revenue scale and a huge technology gap, could not compete with top companies in the sector, such as Texas Instruments, Analog Devices, Infineon, Skyworks Solution, ST and NXP.

In respect of the commercial model of IC enterprises, China, as a latecomer, lacks the large-scale IDM enterprises such as Samsung, Intel, SK Hynix, Micron, Texas Instruments and so on. The most prominent IC enterprises in China include fabless companies HiSilicon and Unisoc, foundry company SMIC and packaging and testing company JCET. Chinese IC enterprises that follow the IDM model mainly focus on middle and low-end IC products due to the technological backwardness. Some of the typical Chinese IDM enterprises in the IC sector, including Tianjin Zhonghuan Semiconductor, Hangzhou Silan and Unigroup (the parent company of Unisoc), have proceeded to an IDM enterprise through large-scale international M&A in the whole IC supply chain supported by the fund. Some scholars have advocated that China should encourage the IDM model and indicated that this is the trend China should follow to develop its IDM enterprises to upgrade the entire supply chain of China's IC industry (Wei 2017; Mo 2017).

In terms of core IP, China's enterprises face a few "choke points" of key technologies that could substantively restrict the growth of the Chinese IC industry. These core IP technologies include licences for ARM architecture for microcontroller units (MCUs), SoCs, CPUs, GPUs and other advanced IP chip design; electronic design automation software for IC design, which is dominated by three American companies, Cadence, Synopsys and Mentor; the technology capacity for 7 nm and 5 nm chips manufacturing; and ASML's EUV lithography machine in foundry. Chinese business elites and policy makers fear that any of ban in the use of technologies based on these aspects of core IP would put China in a second-class status in the IC industry, in which China can only supply mid- and low-end products and relies on importing high-end chips for a long period of time — a reliance that is unstable because of US sanctions.

To sum up, China lags far behind in IC manufacturing equipment and materials, and fabrication but made some impressive progress in IC fabless, in particular HiSilicon's series of 5G chips, and is approaching the global advanced level in packaging and testing, seen from the perspective of the IC supply chain. In terms of IC categories, Chinese companies have the biggest technology gap in memory chips and analog IC, then logic IC and microprocessors. Accordingly, China relies heavily on imports of DRAM and NAND memory chips, analog/power chips, and PC CPU and server CPU chips. Memory chips is the single largest import category, accounting for 36 percent of China's total IC products import. Analog/power chips are the second-largest import category, accounting for 15 percent of the total IC imports, then, successively, 12 percent for mobile phone SoCs, eight percent for PC CPUs and four percent for microprocessors (Institute of China Merchants Bank 2019). China faces choke points in core IP technologies in the whole IC supply chain and will not catch up in the foreseeable future. China also lacks powerful IDM IC enterprises that can integrate the whole IC industrial chain to compete with foreign counterparts.

Problems in the Development of China's Semiconductor Sector

The history of China's semiconductor sector during 1960–2014 indicated the reasons for lagging behind, including lack of investment, talent, faulted development strategy and

37 Phase one of the huge project kicked off at the end of 2016 and phase two began in June 2020 (Zheng 2017; Wallstreetcn.com 2020).

technological block by Western countries. The fund established in 2014 addressed the concern of lack of investment but not the absence of huge R&D expenditure and talent attraction that constitute the foundation of the IC industry.

Fundamentally, the long-existing bureaucracy standard in China's IC sector is to blame.

Under the bureaucracy standard, the government-dominated campaign-style catch-up strategy seeks a short-cut approach for quick success. This approach goes against almost every factor and requirement for a successful IC sector, including long-term accumulation of R&D input and talent dedicated to it, huge and consistent investment, and extremely high trial-and-error costs,[38] and is why China kept failing to narrow the gap with the advanced level in the global IC industry. Specifically, these problems include:

- → No room for real innovation and no tolerance for failure in China's S&T research system, in which government officials in charge do not encourage investment in R&D that focuses on long-term innovation but instead focus on short-term projects with more certainty for success. This problem demonstrates the priorities of the fund, which basically excludes the most fundamental but time-consuming R&D and puts its main investment on IC foundry, packaging and testing, and fabless companies. The problem echoes the dominant philosophy or utilitarian mindset in current Chinese society that seeks a short-cut approach for quick success and holds a disrespectful attitude toward fundamental R&D and innovation.
- → Related to the first problem, most IC investments followed the catch-up strategy and supplied the low-end domestic market, emphasizing quantity instead of quality. Under the strategy, achievements can be realized quickly, and companies can profit from it, although these productions are still generations behind the international advanced level. More importantly, it provides noticeable results, making the performance of supervising bureaucrats look impressive.
- → A lack of talent and the absence of an environment that attracts talent to stay in the IC industry. This also echoes a long-existing problem in the bureaucracy-standard-dominated research culture in China, in which innovative researchers and talented scientists find it difficult to survive.

Widely cited data[39] shows that there is a huge talent gap between the demand and the reality in China's semiconductor industry, which needs 700,000 skilled employees to support its development but only has 300,000 qualified personnel serving in the industry (Gao 2018). There have been some positive changes in recent years, though. Overseas returnees — in particular some top Chinese experts from overseas — continue coming back, and the increase of qualified workers educated in China's universities and institutions would supply more reserve talent. China's top IC companies, such as HiSilicon and JCET, provided generous salaries for their engineers and technicians and attracted more skilled persons to join China's IC sector.

The second type of problem that exists in China's IC sector concerns the disconnection between research and commercially viable products, which is also a typical problem in China's techno-industrial field.

Similar to Arca CPU chips, the case of Loongson CPU chips demonstrated the importance of a market-oriented R&D model for commercially viable products. Government-sponsored and -subsidized IC R&D in state-affiliated institutions and universities, if disconnected with the market, is a dead-end for the development of the IC industry.

Following the national security requirement of "fully controllable" and indigenous CPU chips, the Loongson CPU chose the MIPS structure plus Linux system instead of the mainstream X86 structure by Intel and AMD plus Windows system at the beginning. Without the support of the Wintel (Windows plus Intel) ecosystem, there is a lack of supply-chain support from PC manufacturers and software companies in the market. As a result, Loongson had to develop its full ecosystem, consisting of the supply chain of PC manufacturers and software companies

38 Billions of yuan of investment could be for nothing and return on investment in the IC industry is quite disproportional in a relatively short period.

39 This data is originally from the White Paper on China IC Industry Talents (2017–2018), which was jointly released by China Electronics and the Information Industry Development Research Institute and the Software and Integrated Circuit Promotion Center of the MIIT.

based on the MIPS structure plus Linux system, which are almost non-existent in the market.

Under these circumstances, it seems Loongson was facing a mission impossible. Loongson's long-standing disconnection with the consumer market made it worse. Loongson's isolated research on general purpose CPU chips kept being refused by the market. Its CPU chips are low quality. Loongson 3B1000, 1A and 2I could not even boost the operating system (Hu and Song 2018). After waiting for Loongson's independent CPU chips for 12 years, the Chinese government gave up. In 2013, the "core, high, and basic" project under the National S&T Major Program cancelled its fiscal support for Loongson's independent CPU project and sought instead cooperation with foreign companies such as IBM, AMD and ARM for China's own CPU, based on authorization from these companies.

The third type of problem is that the lack of coordination between government-supported indigenous innovation and the market-oriented approach has constituted a significant obstruction in China's IC industry.

Government direct investment to cultivate flagship IC companies in the late 1990s, such as Project 909, failed due to the global IC market downturn around 2000. The government encouraged both the laissez-faire capitalism approach and state-sponsored projects to develop China's IC industry in the following decade. Government-dominated programs for CPU chips, such as Arca and Loongson, failed in the first few years of the 2000s as they sought an inflexible way for indigenous innovation, which overemphasized "fully independent" and "fully controllable" and rejected technological cooperation with Western companies. The idea of a fully independent controllable supply chain in the IC sector is a self-isolating, self-embargo strategy, in which China's IC industry had already decoupled itself prior to US actions. It goes against the trend of globalization in the IC industry.

During the same period, the market-oriented approach for boosting domestic investment and relying on the global IC supply chain met China's increasing demand for IC products, which prevented Chinese leaders from paying a consistent investment on indigenous innovation for a powerful IC sector after government-funded CPU chip programs failed. It is difficult for the fledging Chinese IC industry to catch up through a free-market competition without substantive and consistent government support in the highly competitive global IC industry with a high density of capital and technology. China's venture capitalists seldom invested in the IC sector before 2018 due to the huge financial risk posed by the long-term investment, huge cost and low return rate in the industry (China Business Network 2018).[40]

A comprehensive and coordinated approach should be encouraged, combining government financial and policy support, as well as a market-oriented approach for the long-term accumulation of technology and talent, aiming to produce commercially viable products and financing from the capital market. The problem is that government support (such as that provided by the fund beginning in 2014 and the promised full support at all costs from the government after the ZTE incident in 2018) again have the potential to go back to another extreme — with more focus on fully independent innovation and less on global cooperation.

The fourth type of problem concerns the lack of capacity for innovation in the IC sector.

Years of catch-up based on the approach of introduction, assimilation and innovation, and market for technology can at best make China a close follower but never a real innovator in the global IC industry. This echoes the lack of sufficient capacity for innovation in China's industries and research institutions. As the case of Project 909 in the 1990s showed, it is impossible to get the up-to-date or core technologies using the market for technology strategy. Generally, most technology acquisitions were out of date and the introduction, assimilation and innovation approach did not translate in practice into indigenous innovation in core technologies. Even if it succeeded after a few years of effort, it would fall behind again as China's competitors did not stop innovation. Innovation in frontier technologies based on existing ones is the only way for China to become a leading country in the IC industry.

In summary, all of these problems contributed to the failure to make breakthroughs in core IC technologies and to narrow the technological gap in China over the past four decades. Under the short-cut approach for quick success, a market-oriented

40 More venture capitalists are investing in China's IC industry, stimulated by the government fund-led investment spree since 2018. See Wu (2020).

Box 1: Reasons for HiSilicon's Rise

First, there was huge R&D investment for technological innovation. HiSilicon started as an R&D section of Huawei's IC department and evolved into an IC design subsidiary of Huawei. In the highly competitive IC sector, featuring fast-evolving technological innovation, prestigious global IC companies put R&D expenditure as their top strategic priority for future growth (KPMG 2019). With full support from Huawei, HiSilicon's huge amount of R&D investment and high R&D intensity lays a solid foundation for its success. HiSilicon's R&D expenditure is among the top 10 in the world, ranking ninth with a figure of US$2.4 billion, an R&D intensity of 21 percent and an annual growth rate of 44 percent in 2019 (*Chip Insights* 2020). The absolute number of R&D expenditure of HiSilicon is much higher than other Chinese IC companies, such as Unigroup, SMIC, ZTE and Hua Hong (Qiu 2020),[41] and its R&D intensity is one of the highest among all the Chinese ICT and top internet companies (see Table 10 in the appendix for R&D expenditure and intensity of Chinese ICT and internet companies). Lack of consistent and high investment on R&D is the crucial reason why most of China's IC enterprises fall further technologically behind their foreign peer companies.

Second, HiSilicon's R&D research has a very close connection with the market. As Huawei's IC design subsidiary, it has an important advantage and supplies SoC for Huawei smartphones. This provided a convenient playground for HiSilicon to test the water of user experiences of its chips and a stable market for its SoC. The big orders from Huawei play a crucial role in HiSilicon's success. In 2018, Huawei's order for chips from HiSilicon amounted to US$21.1 billion (Ouyang and Xu 2019). In 2012, SoC designed by HiSillicon began to supply Huawei's new-generation smartphones. From Kirin 910, its first SoC, until Kirin 970, its latest, HiSilicon supplied its parent company's flagship smartphones for each generation. Huawei's smartphone products use ARM architecture and are supported by the Android system. It was convenient to use the existing ARM plus Android system to provide hardware and software and applications support, which created a favourable environment for HiSilicon to design compatible products and to be accepted more easily in the market.

Third, technological innovation in IC frontiers based on existing technologies constitutes another key factor for HiSilicon's success. HiSilicon's business and products cover four key areas in the IC industry: Kirin series SoC for smartphones and other devices; Kunpeng series server CPU chips for cloud computing at data centres; Ascend series SoC for AI processors; Balong terminal chips and Tiangang base station chips for baseband chips; and other specialized chips for surveillance, mobile cameras, the IoT, set-top boxes and routers. Among them, Kirin series SoCs are a concentrated display of HiSilicon's achievements. With the support from powerful Balong baseband chips, Kirin chips developed into globally advanced SoCs that support 5G communication. For example, HiSilicon's Kirin 980 SoC released in 2018 consists of ARM v8-A ISA (Instruction Set Architecture), ARM Cortex-A76 CPU, ARM Mali-G76 MP10 GPU, baseband chips by Balong 750, TSMC 10 nm FinFET+ fabrication technology and so on. With the solid support of parent company Huawei, HiSilicon's advanced chips, such as Kirin series SoC, are used in its main new generations of smart devices and next-generation mobile communication products. These chips parallel similar products by Qualcomm and Samsung, which even Apple and Intel did not achieve.

Fourth, HiSilicon's huge amount of R&D expenditure make it capable of attracting high-quality talent from around the world for its research and technological innovation.

41 According to the annual report of SMIC, its R&D expenditure in 2019 amounted to US$687.4 million, with R&D intensity at 22 percent (2018 — US$663.4 million with intensity at 17 percent; 2017 — US$509.4 million; and 2016 — US$318 million). It has increased in recent years but is still far below the numbers of HiSilicon. Other companies, such as Hua Hong, are even lower (Qiu 2020).

investment model that prioritized foundry and M&A of IC companies, there were some achievements in a short period, but it would not help strengthen the most-needed R&D and indigenous innovation. The issue of disconnection between academic R&D and the IC industry has not been effectively addressed. Many self-proclaimed advanced, international-level research breakthroughs stopped on paper without any further movement after the researchers and institutions received the government's recognition and rewards. Other problems, such as inconsistent government support and lack of talent and capacity in innovation, all contributed to the slow progress in breakthroughs for core technologies in China's IC industry.

What is the way out for China's IC industry, then, facing all these problems? Huawei's HiSilicon stands out as a rare case of an advanced fabless company among a few successful Chinese IC enterprises. Box 1 describes the reasons for HiSilicon's rise, which acts as a stark contrast to the weaknesses and problems existing in the state-dominated IC development model and demonstrates some traits that may indicate a way forward for some encouraging prospects in China's IC industry.

In short, the huge and consistent investment on R&D research and technological innovation, the close connection between research and market, technological innovation into new frontiers of the IC industry, and qualified talent to support its research and innovation, explain the success of HiSilicon while serving as a foil to the failure of other state-sponsored IC enterprises. In a broad sense, the case of HiSilicon described in the box illustrates the fundamental problems that prevented China's IC industry from achieving breakthroughs in core technologies and narrowing down the technological gap with its advanced foreign peers.

Conclusion

China's decades-long techno-industrial development has primarily followed a government-dominated national campaign-style model through a catch-up approach for quick success. Government-sponsored major S&T programs such as the 863 Program, the 973 Program, the National S&T Major Programs and Made in China 2025, and government-subsidized R&D research carried out by institutions and universities played a major role in China's progress and breakthroughs in many sectors in China's techno-industrial development. In particular, this model helped achieve success in certain high-tech industries and sectors, including nuclear and satellite programs, a space and lunar exploration program and supercomputing, as well as in some advanced manufacturing fields, such as high-speed rail, hydropower equipment, and UHV power transmission and transformation.

However, this government-dominated catch-up approach did not work in the semiconductor industry and other sectors, such as automobiles. The reasons are complicated but, to a large extent, these failures in key technological breakthroughs can be attributed to the long-standing problems in China's S&T research system. The case of China's semiconductor industry showed that a market-oriented approach, close connection between research and the market, the support of a full industrial supply chain, and consistent and huge R&D expenditure and capital investment are necessary to achieve success in the sector, which features a highly competitive atmosphere, high talent and capital intensity, a high cost of trial and error, and fast-evolving technology. China's government-controlled S&T research system and correlated government-dominated campaign-style catch-up approach for techno-industrial development, however, restricted China's capacity to develop into a real technological powerhouse in the semiconductor industry and related sectors.

Technological innovation needs a flexible, relaxed and supportive systemic environment in which innovation is encouraged and failure is tolerated. A research system dominated by government officials instead of technological experts caused many deep-rooted problems that severely restricted S&T achievements and hampered findings. Disconnection between research and the market is another problem in China's government-dominated research system and state-sponsored projects. China's catch-up approach in technological innovation has proven to be ineffective for achieving supremacy in technological and scientific growth. Exploration in new frontiers based on existing technologies for leading innovation is supposed to be the right path. But China's government-dominated S&T research system, which frequently prioritizes