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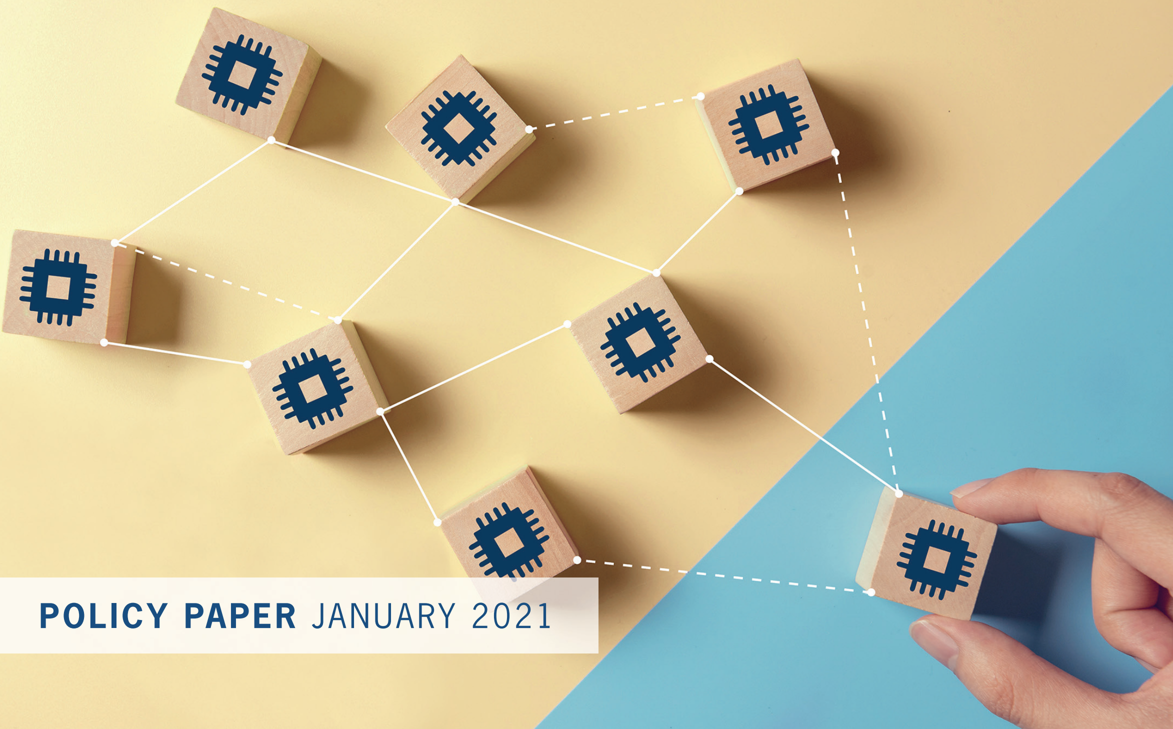
The Weak Links in **China's Drive for Semiconductors**



POLICY PAPER JANUARY 2021

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There is no desire more natural than the desire for knowledge

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INTRODUCTION

In 2019, China imported USD 304 billion worth of semiconductors – more than oil, and more than its total imports from its largest trading partner, the European Union[1]. Driven by China's leading position in electronics manufacturing, a huge domestic market and steady policy support, China's integrated circuit (IC) industry is strong, growing rapidly, but still lagging behind the global market leaders in all segments of the industry. Moreover, only 15.7% of its consumption of semiconductors was manufactured on Chinese soil in 2019[2]. **The world's largest consumer market for semiconductor and integrated circuits depends on foreign suppliers not only for finished processors and other chips, but also for critical equipment and software at each stage of the value chain** – from design to manufacturing and packaging.

For a long time, interdependence was a major asset for China, irrigating the rapid growth of its microelectronic industry. Huawei, through its subsidiary HiSilicon, was able to design and manufacture chips for cutting edge smartphones and 5G telecommunication infrastructure by relying on free access to the global supply chain.

This period may be coming to an end. **The United States, under the Trump administration, has identified semiconductors as a major vulnerability of China. It has exploited China's dependence on foreign technology through the use of technology transfers tools,** especially export controls targeting the military end-users of IC technology. In the past two years, the semiconductor industry has emerged as a central theater of the US-China rivalry. Initially narrowly focused on Huawei and its affiliates, the restrictive regime is gradually expanding to other end-users of IC technology, including the Chinese semiconductor industry itself. The early signs suggest that the Biden administration by and large will continue this increasingly restrictive approach to transfers of semiconductor technology to China.

This has sparked a sense of urgency in Beijing. Prior to the Trump offensive, China had certainly already set ambitious targets – overly ambitious – for its semiconductor industry. Its 2015 plan "Made in China 2025" set the aim of producing 40% of the country's consumption in 2020 and 70% by 2025. The plan to reach self-reliance is now being accelerated. The 5th plenum of the 19th Central Committee – the key political gathering that approved the political orientations of the next five-year plan

1 "China's chip imports expected to exceed $300 billion this year", *Cntechpost*, August 26, 2020, https://cntechpost.com/2020/08/26/chinas-chip-imports-expected-to-exceed-300-billion-this-year/
2 "China to Fall Far Short of its "Made-in-China 2025" Goal for IC Devices", *IC Insights*, May 21, 2020.

(2021-2026) and the country's strategic goals for 2035 – concluded that "scientific and technological autonomy is the pillar of China's national development strategy" (把科技自立自强作为国家发展的战略支撑)[3].

But if China's "innovation-driven development strategy" (创新驱动发展战略) is to succeed, catching up in semiconductors is essential. **Semiconductors are a special industry that deserve high strategic prioritizing by governments engaged in technological competition,** because it is an enabler – it is the steam engine of the ongoing revolution in Information and Communication Technologies (ICT). **Semiconductors are central to all industrial endeavors for which China seeks global leadership,** from military power to the pure digital economy linked to the 5G transformation – artificial intelligence, cloud computing and the Internet of Things. If China remains vulnerable to foreign controls over technology transfers targeting its semiconductor industry, it will have a much lesser chance to reach the objectives announced by Xi Jinping at the 19th National Congress of the Chinese Communist Party in 2017: **to make China a technologically innovative, internationally leading power with a world-class army by 2050[4].**

Today, no other industry in China shows a wider gap between stated policy goals and the technological reality. Semiconductors are the best illustration of Xi Jinping's 2016 statement that "our dependence on core technology is the biggest hidden trouble for us"[5]. China's semiconductor predicament can only be compared to the persistent difficulties China faces to manufacture engines domestically for its civilian and military aircraft industry. This comes in stark contrast to how impressively China has successfully caught up in many other technology-intensive sectors, from its space program to nuclear energy and high-speed trains.

This policy paper analyzes the semiconductor value chain to highlight the balance between interdependence and chokepoints (section 1); describes the state of the Chinese semiconductor industry, from equipment to IC design and manufacturing, identifying its strengths and its areas of dependence on foreign technologies (section 2); provides an analysis of the strengthening of technology transfers controls in

3 "中国共产党第十九届中央委员会第五次全体会议公报" (Communiqué of the 5th plenum of the 19th Central Committee of the Communist Party of China), *Xinhua*, October 29, 2020, http://www.xinhuanet.com/politics/2020-10/29/c_1126674147.htm

4 Xi Jinping, "Secure a Decisive Victory in Building a Moderately Prosperous Society in All Respects and Strive for the Great Success of Socialism with Chinese Characteristics for a New Era", delivered at the 19th National Congress of the Communist Party of China, October 18, 2017. http://www.xinhuanet.com/english/download/Xi_Jinping's_report_at_19th_CPC_National_Congress.pdf

5 "Core technology depends on one's own efforts: President Xi", *People's Daily*, April 19, 2018, http://en.people.cn/n3/2018/0419/c90000-9451186.html

the United States under the Trump administration and an early analysis of what can be expected from the Biden administration (section 3); reviews China's current industrial policies to overcome its weaknesses and vulnerabilities (section 4). It argues in its conclusion (section 5) that **China's plans are excessively ambitious given the international environment and the domestic brakes it faces.** But if the history of reforms and opening is any guide, it teaches that despite the constraints, progress has to be expected as a result of strong policy guidance and determination.

The final section draws implications and recommendations for the European semiconductor industry. **Europe will remain at the intersection of two forces.** On the one hand, the US approach to technology transfers. On the other hand, China's mix of industrial policies and drive to obtain foreign technologies by all available means, with Europe a target of choice. The US-China tech war has exposed the vulnerabilities of the semiconductor supply chain. **There is a need for Europe to work on its strengths to reduce jeopardy to its technology access by geopolitical risks.** A defensive approach is needed in coordination with the United States but given Europe's existing strengths and the post-Covid 19 recovery packages, this is also a time of opportunity for targeted support to strengthen the competitiveness of the European microelectronics industry.

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I

THE SUPPLY CHAIN: INTERDEPENDENCE AND CHOKEPOINTS

The word "semiconductor" refers to a material, the electric conductivity properties of which are the basis of electronics. The term is used to refer to integrated circuits that are manufactured by assembling transistors printed on silicon, germanium, or gallium arsenide semiconductor wafers. Since the production of the first integrated circuit by Texas Instruments in 1958, the semiconductor industry has become globalized, concentrated, specialized, interdependent, and driven by colossal research and development investment. **It is currently concentrated in the United States, China, South Korea, Taiwan, Japan, and Western Europe and is structured by complex value chains linking its main players and their subcontractors.** The industry produces two main types of integrated circuits: processors (logic and analog, such as graphic and computer processing units) and memory.

1. From design to packaging: interdependence and chokepoints

To understand China's efforts, it is essential to outline how this industry operates[6]. There are three main stages in the production chain: design, manufacturing, and assembly, testing and packaging. **Only a few industry giants – integrated device manufacturers, or IDMs – integrate all three phases.** The market leaders by revenue are Intel, Samsung, SK Hynix and Micron Technology. Europe has three IDMs in the top twenty – Infineon, NXP and STMicroelectronics.

The value chain starts with design – the specialty of "fabless" manufacturing, semiconductor companies without a physical production facility, known as a fab. Fabless accounts for 38.5% of the world's integrated circuit sales volume. **The fabless model explains why the US dominates the upstream in the semiconductor industry**

6 For an excellent and more detailed summary of the semiconductor industry: Jan-Peter Kleinhans, Nurzat Basakova, "The global semiconductor value chain, a technology primer for policymakers", Stiftung Neue Verantwortung, October 2020, https://www.stiftung-nv.de/de/publikation/global-semiconductor-value-chain-technology-primer-policy-makers

with 47% of world sales, even though no American foundry today masters the most advanced generations of integrated circuit manufacturing[7]. Broadcom, Qualcomm and Nvidia in the United States, HiSilicon in China (Huawei's semiconductor subsidiary), MediaTek in Taiwan are all fabless IC companies. UK's ARM has a specialization in intellectual property core for the conception of integrated circuits. Its architecture dominates the global chip design market.

This US upstream domination is accentuated by the fact that fabless companies depend on the design software tools of four companies to conceive new integrated circuits: three American, Cadence, Synopsis, Ansys, and one German, Siemens EDA (until recently named Mentor Graphics), acquired by Siemens in 2017 from the US, but with intellectual property that essentially remains American. **These four companies control 90% of the market for electronic design automation (EDA) software,** which is used in the conception of all integrated circuits, regardless of their generation, but which grows particularly complex and technology-intensive with the most advanced industrial processes.

Table 1: Top 35 world's semiconductor companies by revenue (2019)[8]

Company	Country	Business Model (major technology segment)	2019 Revenue (billion USD)
Intel	USA	IDM (NAND, CPUs, GPUs)	65.8
Samsung Electronics	South Korea	IDM (NAND, DRAM)	52.2
TSMC	Taiwan	Contract foundry	35.8
SK Hynix	South Korea	IDM (NAND, DRAM)	22.4
Micron	USA	IMD (NAND, DRAM)	20
AMAT (Applied Materials)*	USA	SME	17.2
Broadcom	USA	Fabless (SoCs)	15.3
ASE Technology Holding (SPIL included)	Taiwan	OSAT	13.8
Qualcomm	USA	Fabless (CPUs)	13.5

.../...

7 Semiconductor Industry Association, 2020 State of the US Semiconductor Industry, June 2020, https://www.semiconductors.org/wp-content/uploads/2020/06/2020-SIA-State-of-the-Industry-Report.pdf
8 The numbers are limited to the semiconductor business segment when relevant. Sources: Gartner, Annual Filings, Annual Reports, Press releases, Gartner.

Company	Country	Business Model (major technology segment)	2019 Revenue (billion USD)
Texas Instruments	USA	IDM (analog, automative, SoCs, FPGA)	13.2
ASML Holding	The Netherlands	SME (extreme ultra violet lithography)	13.2
Nvidia	USA	Fabless (GPUs and SoCs)	10.9
TEL (Tokyo Electron)**	Japan	SME	10.4
Lam Research***	USA	SME	10
Sony **	Japan	IDM (CMOS image sensors)	9.8
STMicroelectronics	France, Italy	IDM (analog, automative, SoCs, sensors)	9
Infineon Technologies****	Germany	IDM (analog, automative, sensors)	8.9
Kioxia Holdings	Japan	IDM (NAND)	8.8
NXP Semiconductors	The Netherlands	IDM (analog, automative, SoCs, sensors)	8.7
MediaTek	Taiwan	Fabless (CPUs)	8.2
Western Digital/ SanDisk *****	USA	IDM (NAND)	7.8
HiSilicon	China	Fabless (SoCs)	7.4
AMD (Advanced Micro Devices)	USA	Fabless (CPUs, GPUs)	6.7
Renesas Electronics	Japan	IDM (analog, automative, CPUs, sensors)	6.6
Analog Devices******	USA	IDM (analog, SoCs, sensors)	5.9
KLA-Tencor***	USA	SME	5.8
ON Semiconductor	USA	IDM (analog, automative)	5.5
Microchip Technology	USA	IDM (analog, automative, SoCs, sensors)	5.3
Synopsys******	USA	EDA	3.4
JCET Group	China	OSAT	3.3
Xilinx*******	USA	Fabless (FPGA, SoCs)	3.2
SMIC	China	Contract foundry	3.1
Cadence Design Systems	USA	EDA	2.3
Tsinghua Unigroup	China	IDM (memory and other IC)	2.2
ARM**	UK	IP blocks	1.9

* Fiscal year ended October 2019. ** Fiscal year ended March 2020. *** Fiscal year ended June 2020.
**** Fiscal year ended September 2019. ***** Fiscal year ended July 2020.
****** Fiscal year ended November 2019. ******* Fiscal year ended April 2020.

Once designed, the semiconductors are ordered from the foundries. **High-end foundries are extremely capital-intensive, which explains the high concentration of the global market.** Pure-play foundries and IDMs share a market dominated by the Taiwanese company Taiwan Semiconductor Manufacturing Corporation (TSCMC). **TSMC is the pioneer of the contract-foundry model.** It has achieved continuous technological upgrading through orders from the most advanced fabless IC designers. TSMC is far ahead of the other pure-play foundries such as SMIC (China), UMC (Taiwan), and GlobalFoundries (United States), by its share of the world foundry market (around 50%), its turnover (USD 36.4 billion in 2019), its market capitalization, and its three to four generation technological lead over all its competitors. Its only remaining competitor for the most advanced semiconductor is Samsung. **Indeed, the high-end segment of the industry is a duopoly – this has important implications for the digital economy,** which relies much more than other industries on the further miniaturization of integrated circuits. The foundry capacity of European top three IDMs relies on the mature 28 nm generation of semiconductors, which has many industrial applications, including in the lucrative automotive industry.

Foundries also require highly specialized equipment for manufacturing. The semiconductor equipment (SME) industry is dominated by three American companies – Applied Materials, Lam Research, and KLA-Tencor – and one European, ASML of the Netherlands. This Dutch company has a monopoly on extreme ultraviolet lithography technology, which is required to etch semiconductors from the 7-nanometer generation onwards and is thus essential to reach the 3/2 nanometer nodes[9]. **A single ASML machine costs about USD 250 million. Its only users today are Samsung and TSMC.** Several EUV lithography technologies are subject to multilateral export controls under the Wassenaar Arrangement, as analyzed in detail below. EUV is an upgrade of deep lithography technology (DUV), produced by ASML and used in foundry processes for earlier generations of semiconductors – including by foundries in China.

Finally, companies in the assembly, testing, and packaging industry produce close to 6% of the chain's total output. This USD 30 billion industry is dominated by Taiwanese (ASE, SPIL, Powertech) and Chinese firms (JCET Group, Tongfu Microelectronics, Tianshui Huatian Technology) and one American firm, Amkor Technology. **This final stage is relatively less skill and capital-intensive than the earlier manufacturing stage.** This explains why this was the first segment of the industry to be offshored to East Asia as early as the 1960s. This shift was a decisive factor behind

9 Carrick Flynn, "The chip-making machine at the center of China's dual-use concerns today", *Tech Stream*, June 30, 2020, https://www.brookings.edu/techstream/the-chip-making-machine-at-the-center-of-chinese-dual-use-concerns/

the emergence of a semiconductor industry in Taiwan and was important also for the development of the sector in China[10].

This schematic description of the industry points to an intricate and complex interdependence in the value chain. **Division of labor and specialization have been the key recipe for the success of the industry, enabling an increase in performance progressing hand in hand with a constant decrease of the production costs.** The production of a new chip means constant back and forth between conceivers, tools and software designers, equipment makers and foundries, in a complex innovation process that rests on the strengths of all actors. Indeed, the race to reduce the size of transistors is also a race to upgrade the software tools that enable their production. **As a result, the value chain is also a chain of trust. Testing companies, for example, have in-depth access to the intellectual property of a particular integrated circuit –** this even creates a niche for particularly secure assembling, testing and packaging solutions.

2. The 7-nanometer threshold

In 1947, only one transistor could be installed on a silicon wafer the size of confetti. By 1988, the same size wafer could hold a million transistors[11]. The industry began to use nanometers as a reference measure as early as 1987. Since the late 1950s, Moore's Law has structured the progress of the semiconductor industry. **The law empirically predicted the densification of transistors on a chip, at the rate of a 100% increase every two years.** The space between two transistors has thus decreased from 10 micrometers in 1971 to 5 nanometers in 2020. It is soon to drop to 3 nanometers, and ultimately 2 nanometers – widely seen today as a physical barrier after which further miniaturization will no longer be possible. Each upgrade following Moore's Law has allowed enormous competitive advantages, gains of speed and increases in the production capacity. On a 200 mm wafer, 5 nm process technology allows 15 more times the number of transistors than 30 nm technology.

Today, only TSMC and Samsung manufacture 5-nanometer generation semiconductors. The two corporations are increasing their lead over Intel, which announced in

10 OECD, Measuring distortions in international markets: the semiconductor value chain, *OECD Trade Policy Paper no. 234*, December 2019, http://dx.doi.org/10.1787/8fe4491d-en

11 Louis Mexandeau, « L'évolution de l'industrie des semi-conducteurs » (The evolution of the semiconductor industry), Report n° 180 (1989-1990) to the French parliamentary office for the evaluation of scientific and technological choices, December 22, 1989.

2020 a considerable delay of its 7-nanometer generation production facility project, which would not be operational before 2023. Thus, Intel is left with no choice but purchasing chips from TSMC for its processors requiring 7 nm technology and below[12]. **The TSMC-Samsung duopoly is maintaining its lead at a very high cost.** In Tainan, a city in southern Taiwan, TSMC has started in the second semester of 2020 production of 5-nanometer etched semiconductors, with a full order book dominated by Apple. **Tainan's TSMC facilities are due to produce 3-nanometer generation semiconductors starting in 2022/2023, with an estimated investment of USD 20 billion[13].** TSMC's average annual research and development budget is close to 9% of its revenue; it exceeded USD 3 billion in 2019 and USD 3.5 billion in 2020[14]. In order to take over global leadership in the non-memory segment, Samsung has announced an investment budget of USD 100 billion for its semiconductor subsidiary in the next decade[15]. **While this capital intensity is not an impossible barrier for the Chinese state to overcome, as we shall see, the leading-edge technology entails human resources and production process management challenges that are severe obstacles to a technological leap forward,** in addition to ensuring the integrity of the supply chain, in particular for chemicals and equipment tools. It also requires mastering some chokepoint technologies, such as EUV lithography.

These staggering figures cover a tangible reality. In 2020, smartphones, from mid-range products upwards, need at least a 7-nanometer manufacturing process for their microprocessors. With the advent of 5G, the most high-performance phones and certain applications will even need 5-nanometer generation semiconductors to make the most of the network's power. By the end of 2020, the new iPhones already incorporate TSMC's 5-nanometer technology. Apple demand alone is sufficient to fully book the 5nm process capacity of the Taiwanese foundry[16]. And **once 3-nanometer semiconductors go into production in 2022/2023, Tainan's TSMC complex will only strengthen its already crucial role as a hardware hub for the 5G transformation.**

What is important to note here is that the cutting-edge integrated circuit technology has mainly pure digital applications, in computers, handset devices and

12 "Intel's 'stunning failure' heralds end of era for US chip sector", *Taipei Times*, July 26, 2020, https://www.taipeitimes.com/News/biz/archives/2020/07/26/2003740544

13 "TSMC to invest record $20bn in advanced 3-nm chips", *Nikkei Asian Review*, December 7, 2017, https://asia.nikkei.com/Business/Electronics/TSMC-to-invest-record-20bn-in-advanced-3-nm-chips2

14 "TSMC boosts R&D to hold lead", *Taipei Times*, April 23, 2020, https://taipeitimes.com/News/biz/archives/2020/04/23/2003735105

15 "Samsung Electronics' R&D Investment in 2019 Tops 20 Tril. Won for First Time", *Business Korea*, February 27, 2020, http://www.businesskorea.co.kr/news/articleView.html?idxno=41971

16 "Apple orders to fill up TSMC 5nm process capacity", *DigiTimes*, September 17, 2020, https://www.digitimes.com/news/a20200917PD210.html

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telecommunications. In the next five years, 5, 3 and 2 nanometer nodes will equip the new generations of CPUs, cloud services data centers, including their AI chips, servers and the high-end smartphones. This is by far the market segment with the highest added value. It is important to note here that the production cost of processors to be integrated into mobile devices is higher because of their needs of energy dissipation and performance. This explains, for example, why Intel dominates the market of servers without 7 nm foundry capacity. **In sum, the ICT hardware industry is a powerful driver for the constant modernization of integrated circuits.** In addition to personal computers and smartphones, computer servers, cloud service providers and crypto-currency mining all drive the demand for computer and graphics processing units. Looking ahead, developments in 5G, edge computing, and artificial intelligence/machine learning, as well as continued development in automotive, will continue to make semiconductors central to global economic competition, and possibly great power rivalry.

TSMC and Samsung hold all the cards to make the most of the ongoing new digital revolution since the global digital economy entirely depends on their advanced foundry process. But it is important to note **that in practice, the world has a higher dependence on TSMC than Samsung.** This is because Samsung, as an electronics conglomerate, consumes the lion's share of its production of integrated circuits.

3. The military end-uses of semiconductor technology

Previous generations of semiconductors continue to find many applications. The 14-nanometer generation is sufficient for entry-level 4G and even for some processor architectures compatible with 5G. Integrated circuits etched at 28 nm, 40 nm, 55 nm, 65 nm, 90 nm, and up to 350 nm find many industrial applications in the automotive, robotics, and armament sectors, but also in less advanced consumer electronics and in public infrastructure such as management of the electricity grid or of water resources. For example, Wi-Fi and GPS technology both work with generations before 14 nanometers. The Chinese BeiDou Navigation Satellite System integrates a domestically manufactured 28-nanometer engraved chip. **The automotive industry is two to three generations of semiconductors behind the pure digital applications, mainly for reasons of reliability and thus safety.**

Military applications are relatively negligible for the semiconductor industry from the perspective of their share of sales revenue – around 1% in 2003 according to a report by the US National Defense University, 1.1% in 2019 according to Deloitte[17].

But market share fails to measure the strategic value of the industry from the angle of the military balance of power. In the military field, extreme miniaturization is so far not necessary for weapons systems and command and control systems. **The key elements are the reliability and specific design of the integrated circuit.** Advancement in semiconductor technology naturally fuel military competition between states. Monique Chu of Southampton University has highlighted **a "spin-on" phenomenon whereby technology diffusion is driven by the civilian industry, which carries across to the arms industry.** Transistors, integrated circuits, and lithography equipment are innovations stemming from the civilian sector[18]. The first military subfield to have benefited from the microelectronic revolution is missile guidance and control. The Minuteman II intercontinental ballistic missile developed in 1962 was the first weapons system to incorporate integrated circuits. Today, defense electronics are a critical element of superiority for control, command, and intelligence during military operations. **They nevertheless offer specific vulnerabilities to an attacker,** such as possible paralysis via electromagnetic pulse strikes or direct attacks against integrated circuits that can be preinstalled during production to program an alteration in their behavior in times of conflict. The disruption of a fire control system or military communication channels is a realistic scenario. For any advanced arms industry, this creates offensive options and defensive challenges.

While the arms industry does not depend today on the most advanced generations of integrated circuits, this may change in the future as military operations increasingly integrate new digital technologies. This is partly in anticipation of future research and development in the military sphere that **the Trump administration has worked hard to convince TSMC to build a highly subsidized fab in Arizona.** The US digital economy needs a resilient access to the integrated circuits designed at the 5-nanometer node. Production in Taiwan is insufficient to meet future demand[19]. But while the pure digital economy should take the lion's share of the fab's production, the US arms industry will also benefit from chips production on US soil specifically designed for its needs, as local production decreases the risk of sabotage.

17 "Electronics Industry Study Report: Semiconductors and Defense Electronics", National Defense University, 2003, https://apps.dtic.mil/dtic/tr/fulltext/u2/a524792.pdf. "Semiconductors – the Next Wave Opportunities and winning strategies for semiconductor companies", *Deloitte*, April 2019, https://www2.deloitte.com/content/dam/Deloitte/cn/Documents/technology-media-telecommunications/deloitte-cn-tmt-semiconductors-the-next-wave-en-190422.pdf
18 Monique Chu, *The East Asian Computer Chip War*, Routledge, 2013.
19 "Phoenix okays development deal with TSMC for $12 billion chip factory", November 18, 2020, https://www.reuters.com/article/us-tsmc-arizona/phoenix-okays-development-deal-with-tsmc-for-12-billion-chip-factory-idUSKBN27Y30E

OVERVIEW OF THE CHINESE SEMICONDUCTOR INDUSTRY

China is one of the world's six leading poles for semiconductor design, manufacturing and packaging. In 2019, the total output of China's semiconductor industry was USD 29.4 billion – a 5.9% global market share[20]. China's self-reliance ambition concerns the whole IC supply chain, from semiconductor equipment, IC design software, manufacturing tools, IC design and manufacturing, to assembly, packaging and testing.

However, despite having companies ranking in the world's top 20 covering the entire spectrum of semiconductor production, **there is still a long way ahead before China reaches strategic autonomy.** In fact, if strict controls over technology transfers are maintained, self-reliance may be out of reach in the foreseeable future. This does not mean that China has not achieved impressive progress. But successes in the past two decades have relied **on a pattern global interdependence in the microelectronic industry which today is shaken off by geopolitics and strategic competition.** Offshoring and access to US technologies have enabled the Chinese industry to develop impressive strengths in design (especially HiSilicon, Huawei's semiconductor fabless subsidiary) and in testing and assembly. In addition, the world's fifth and sixth foundries by sales in 2019, SMIC and Hua Hong Group, are from China.

20 Industry, Science and Technology International Strategy Center, "Introduction of Taiwan Semiconductor Industry Current Status", Industrial Technology Research Institute, Taiwan, September 18, 2020.

Table 2: Top 12 Chinese semiconductor companies by revenue (2019)[21]

Company name	Ownerships	Business Model (major technology segment)	2019 Revenue (billion USD)
HiSilicon	Private	Fabless (SoCs)	7.4
JCET Group	Public	OSAT	3.3
SMIC	Public	Contract foundry	3.1
Tsinghua Unigroup	Public	IDM (memory and other IC)	2.2
OmniVision	Public	Fabless (image sensors)	1.7
Bitmain	Private	Fabless (ASIC)	1.6
Tongfu Electronics *	Private	OSAT	1.2
Tianshui Huatian Technology	Private	OSAT	1.2
Hua Hong Semiconductor	Private	Contract foundry	0.9
Goodix	Public	Fabless (fingerprint recognition)	0.9
ZTE Microelectronics	Public	Fabless (SoCs)	0.7
Naura	Public	SME	0.6

* Formerly Nantong Fujitsu Microelectronics.

1. Fabless

China has pockets of excellence in IC design. HiSilicon, Huawei's semiconductor subsidiary (90% of its sales in 2019 were internal transfers to Huawei technology), has been a leading innovator in telecommunications integrated circuits[22]. HiSilicon has designed the Kirin processor, which equips many of Huawei's high-end smartphones and was originally manufactured by TSMC in Taiwan using 7nm process technology. However, by complying with US sanctions, the Taiwanese foundry announced that no new order from Huawei and its subsidiaries would be taken and stopped shipments in September 2020[23]. The future of HiSilicon is highly dependent on future US licensing policies, and on China's push to accelerate innovation and autonomy. One of Huawei's first response to US sanctions was the launching of the Tashan Project (塔山计划), which includes

21 Sources: Gartner, https://tech.163.com/20/0511/11/FCBGV2AM00098IEO.html, *Equal Ocean*, DNB, Zhihu.
22 "China-Based HiSilicon's Time in the Top-10 Ranking May be Short Lived", *IC Insights*, August 11, 2020, https://www.icinsights.com/news/bulletins/ChinaBased-HiSilicons-Time-In-The-Top10-Ranking-May-Be-Short-Lived-/
23 "TSMC Won't Sell Chips to Huawei in Fourth Quarter", *Caixin*, October 16, 2020, https://www.caixinglobal.com/2020-10-16/tsmc-wont-sell-chips-to-huawei-in-fourth-quarter-101615215.html

the construction of a 45 nm technology production line that excludes US technology by the end of 2020, and explores options for the construction of a 28 nm production line[24]. **That would be a first step towards improved resilience, but still a long shot from mastering the most advanced foundry processes.**

In the near future, other Chinese smartphone companies, such as Oppo and Xiaomi, may follow Huawei's path and challenge Apple, Qualcomm and Samsung in developing a system-on-chip processor for their high-end smartphones, but they will need contract manufacturers from outside China as long as no Chinese foundry masters 7 nm technology[25]. At the end of 2020, they were taking advantage of Huawei's predicament to buy the new 5G processor designed by Qualcomm from the US and to manufacture new 5G smartphone models[26].

Two other IC design companies deserve particular attention:

- **OmniVision Technologies,** Inc., publicly traded as part of Will Semiconductor, is a leading designer of image sensors, application-specific integrated circuits such as IoT processors, sensor bridges and automotive solutions.
- **Huada Semiconductor,** a listed subsidiary of the state-owned defense electronics giant China Electronics Corporation (CEC), is deeply embedded in China's military ecosystem. Huada is the leading subsidiary in a larger ecosystem that covers the whole spectrum of the industry, from R&D to manufacturing and design and software tools. CEC's policy goal, as a central SOE under the guidance of the State-owned Assets Supervision and Administration Commission (SASAC), is to build a "national team for network security and information technology industry"[27].

24 "华为被断供首日:海思安防等芯片价格暴涨 "涉美"项目大量被砍" *(The first day of Huawei being cut off: the price of chips such as Hessian security skyrocketed, a large number of "U.S.-related" projects were killed), Sohu*, September 15, 2020, https://www.sohu.com/a/418610557_110683

25 "How SMIC Can Keep Up With Advanced Process Technologies, Part 2", *EETAsia*, July 20, 2020, https://www.eetasia.com/how-smic-can-keep-up-with-advanced-process-technologies-part-2/

26 "Qualcomm's new flagship 5G chip embraced by major Chinese smartphone makers – except Huawei", *South China Morning Post*, December 2, 2020, https://www.scmp.com/tech/big-tech/article/3112232/qualcomms-new-flagship-5g-chip-embraced-major-chinese-smartphone

27 Website of China Electronics Corporation, https://en.cec.com.cn/jtjj/list/index_1.html

Table 3: Top 10 Chinese IC Design Companies by Revenue (USD Billion)[28]

2018 Rank	2019 Rank	Company	2018 Revenue	2019 Revenue	2019 Growth Rate (%)
1	1	**HiSilicon**	6.1	7.4	22%
2	2	**Tsinghua Unigroup**	2.3	2.2	-2%
4	3	**OmniVision**	1.4	1.7	18%
3	4	**Bitmain**	1.7	1.6	-6%
5	5	**ZTE Microelectronics**	0.9	0.7	-18%
7	6	**CIDC Group**	0.6	0.6	-3%
8	7	**Nari Smart Chip**	0.6	0.6	-4%
6	8	**ISSI**	0.6	0.5	-24%
10	9	**Giga Device**	0.3	0.5	39%
9	10	**Datang Semiconductor**	0.4	0.4	-4%

Looking ahead, **the power of Chinese internet platforms like Alibaba, Baidu and Tencent and their business growth into cloud, AI, the Internet of Things and systems for autonomous vehicles will be a powerful driver for the further growth of Chinese IC design[29].** In addition, the Chinese start-up scene has impressive strengths in AI chip design, with companies like Enflame, Cambricon, a spin-off from a research team at the Chinese Academy of Sciences[30].

28 Source: IC Insights.

29 Scott Harold, Justin Hodiak, "China's Semiconductor Industry: Autonomy Through Design?", Institut Montaigne, September 27, 2020, https://www.institutmontaigne.org/en/blog/chinas-semiconductor-industry-autonomy-through-design

30 "Tencent invests in Chinese A.I. chip start-up as part of $279 million funding round", *CNBC*, January 5 2021, https://www.cnbc.com/2021/01/06/tencent-invests-in-chinese-ai-chip-start-up-enflame.html. "Chinese AI Chip Maker Cambricon Share Price Surges 350% on IPO Debut, Raising US $369 million", *Synced*, July 20, 2020, https://syncedreview.com/2020/07/20/chinese-ai-chip-maker-cambricon-share-price-surges-350-on-ipo-debut-raising-us-369-million/

2. IC manufacturing: Foundries

China's leading pure-play foundry is Semiconductor Manufacturing International Corporation (SMIC), a private company based in Shanghai. SMIC was created in 2000 and is now the world's fifth foundry in sales volume, behind TSMC, Samsung, GlobalFoundries, and UMC. SMIC has seven fabs in Beijing, Tianjin, Shanghai and Shenzhen. It has been producing 14-nanometer generation semiconductors since 2019 but had yet to achieve mass production in early 2021, due to severe bad yield issues. In the first quarter of 2020, 14 nm technology only amounted to 1.3% of SMIC's revenue, by comparison with 32.6% for 55/65 nm[31]. SMIC is currently working on developing the 7-nanometer generation and has communicated on a possible 12-nanometer intermediate generation.

SMIC is thus six years behind the leaders – TSMC and Samsung reached operational production of the 14-nanometer etching process in 2013. A majority of SMIC's sales go to the Chinese domestic market – 59% in 2019, and up to 66% in the first semester of 2020[32]. In 2019, SMIC's top customer was HiSilicon, with 23% of its sales, followed by Qualcomm, Broadcom, and two Chinese IC design firms, GalaxyCore and GigaDevice[33]. SMIC's 14 nm technology has been adopted by HiSilicon to manufacture the processors of some of Huawei's entry-level smartphones.

SMIC is the target of export control measures. Its purchase of ASML lithography equipment has yet to be granted or denied as it is examined under the Wassenaar Arrangement and Dutch national export control, creating a major hurdle on SMIC's way to develop 7 nm technology[34]. The United States has also increased its scrutiny of SMIC, **with the Department of Commerce informing American companies that technology transfers to SMIC posed an "unacceptable risk" of being diverted to "military end-use"[35].** SMIC's ties to the Chinese arms industry have been described in an unreleased report produced by US defense contractor SOS International[36]. Nevertheless, **SMIC officially denies producing integrated circuits for military end-users in China.**

31 Semiconductor Manufacturing International Corporation, *Investor Fact Sheet*, 1st quarter 2020, https://www.smics.com/uploads/5ed45dbc/Investor Fact Sheet (1Q2020) - final.pdf
32 "China Forecast to Represent 22% of the Foundry Market in 2020", *IC Insights*, October 13, 2020, https://www.icinsights.com/news/bulletins/China-Forecast-To-Represent-22-Of-The-Foundry-Market-In-2020/
33 Guoyuan Securities, "晶圆代工行业密码"(A Password to the Foundry Industry), July 14, 2020, http://pdf.dfcfw.com/pdf/H3_AP202007141391592160_1.pdf
34 "ASML delays EUV machine shipment to SMIC", *Electronics Weekly*, November 6, 2019, https://www.electronicsweekly.com/news/business/asml-delays-euv-machine-shipment-smic-2019-11/
35 "China's biggest chipmaker SMIC hit by US sanctions", *Financial Times*, September 27, 2020, https://www.ft.com/content/7325dcea-e327-4054-9b24-7a12a6a2cac6
36 "U.S. Considers Cutting Trade with China's Biggest Semiconductor Manufacturer; SOSi Report Cited", *SOS International*, September 5, 2020, https://www.sosi.com/news/u-s-considers-cutting-trade-with-chinas-biggest-semiconductor-manufacturer-sosi-report-cited/

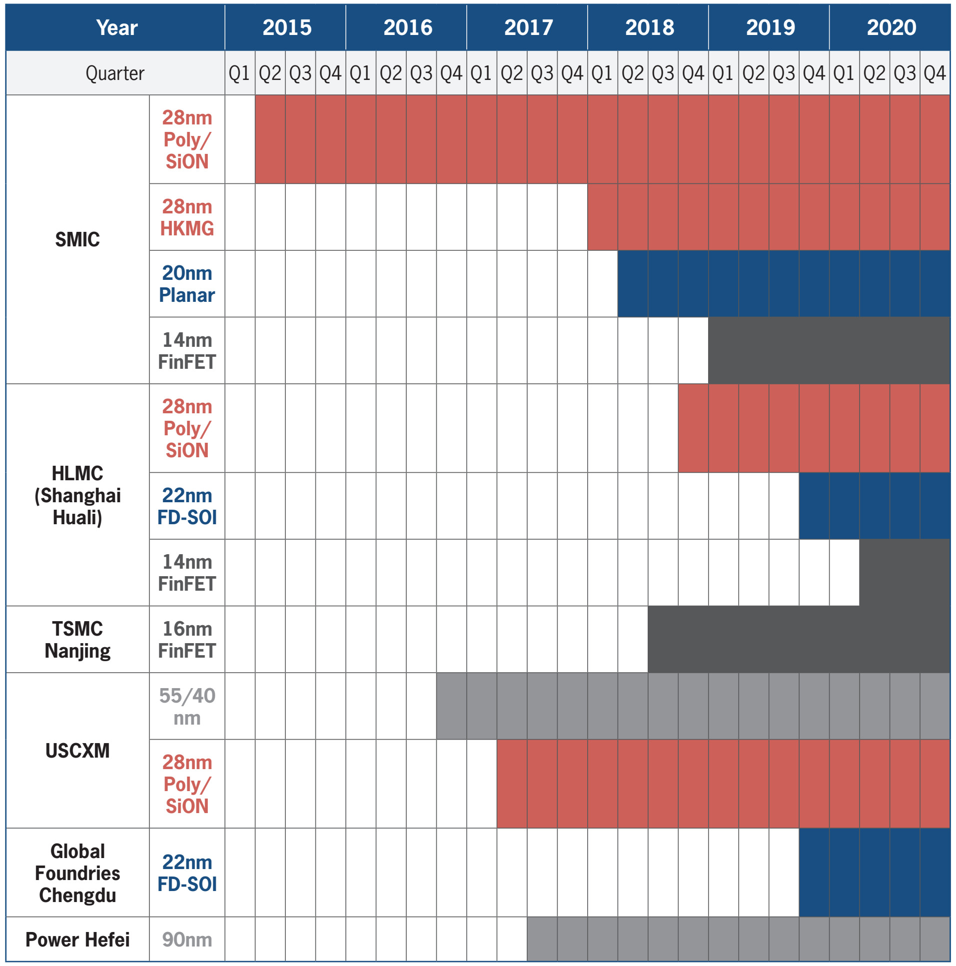
Hua Hong Semiconductor, China's second most advanced pure-play foundry, has four fabs in Shanghai and Wuxi, Jiangsu province. It masters all technical nodes up to 90 and 65 nm. Its products are found in a wide range of industrial applications such as electric cars, wind power and smart home devices[37].

The dramatic failure of Wuhan Hongxin Semiconductor Manufacturing in 2020 **revealed the obstacles to leapfrog in IC manufacturing that have to do with China's bureaucracy – but the story of Wuhan Hongxin is also an interesting case of political push coming from a local government.** Started in 2018, Wuhan Hongxin ambitioned fast catch up with the most advanced foundries, with a goal to reach 3 nm process technology, starting with 14 and 7 nanometers production lines[38]. The Wuhan government issued a statement that Wuhan Hongxin was the first Chinese company to have imported an EUV lithography scanner from ASML, which later proved fake[39]. The fall of Wuhan Hongxin happened despite more than USD 2.1 billion being spent[40]. The downward trajectory was initially revealed by a conflict around the right to use 55 acres of the land where the fab was being built, but what triggered the fall is a funding shortfall. Wuhan Hongxin lost the trust of investors as it failed to complete land acquisition and environmental impact reports according to Caixin[41]. To lead its operations, Wuhan Hongxin had hired as Chief Executive Chiang Shang-yi, the long-time "right-hand man" of TSMC founder Morris Chang, whom he called in 2013 "the most important contributor to TSMC in the past 16 years"[42]. After Wuhan Hongxin's assets were taken over by the State-owned Assets Supervision and Administration Commission for the Dongxihu district government in Wuhan, Chiang Shang-yi described his executive experience as "a nightmare, unfortunately"[43].

Most of the many other Chinese foundries produce mature technology, 55-nanometer generation semiconductors and below. In addition, Chinese IC manufacturing has many international players, as shown by table 4.

37 Huahong Semiconductor Wuxi Limited, "Commencement of construction of Hua Hong's newest base for IC research, development and manufacturing", July 25, 2018, https://www.prnewswire.com/news-releases/commencement-of-construction-of-hua-hongs-newest-base-for-ic-research-development-and-manufacturing-300686170.html
38 "How SMIC Can Keep Up With Advanced Process Technologies, Part 2", *EETAsia*, July 20, 2020, https://www.eetasia.com/how-smic-can-keep-up-with-advanced-process-technologies-part-2/
39 "A RMB130 Billion Semiconductor Project Has Reportedly Failed", *China Money Network*, September 8, 2020, https://www.chinamoneynetwork.com/2020/09/08/a-rmb130-billion-semiconductor-project-has-reportedly-failed
40 "Wuhan's troubled $18.5 billion chipmaking project isn't as special as local officials claimed", *Caixin*, September 4, 2020.
41 "$18.5 Billion Wuhan chip plant in danger of stalling", *Caixin*, August 25, 2020.
42 "Former TSMC executive to join Chinese rival", *Nikkei Asia*, December 22, 2016, https://asia.nikkei.com/Business/Former-TSMC-executive-to-join-Chinese-rival
43 "China's semiconductor dream takes a hit as local authority takes over 'nightmare' Wuhan factory", *South China Morning Post*, November 18, 2020, https://www.scmp.com/economy/china-economy/article/3110368/chinas-semiconductor-dream-takes-hit-local-authority-takes

Table 4: IC Manufacturing in China by generation[44]



44 Source: Yolo, GF Securities Research Center.

3. Memory

Memory technology, in particular system memory (e.g. DRAM) and information backup memory (e.g. NAND flash), is another area of Chinese resolute determination to catch up with the global leaders – an ambition supported by easy access to capital. KPMG China recalls that **the upgrade of telecommunication networks to 5G is a "golden opportunity" for the memory industry, as a new generation of smartphones will require greater memory capacity[45].** Today, like the rest of the world, China's consumer electronics source memory chips from Samsung, SK Hynix and Micron, including through manufacturing facilities in China. The local Chinese production of SK Hynix for DRAM, Samsung and Intel for 3D NAND Flash is important from the perspective of cultivating Chinese human resources and acquiring technology. SK Hynix is the largest investor in Jiangsu province, with a USD 20 billion investment, and China represents 46.6% of the company's sales[46]. SK Hynix, Samsung and Intel are respectively no. 1, 2 and 4 IC manufacturing companies in China by revenue[47].

Despite this overwhelming domination, **two Chinese champions have nevertheless emerged in recent years, thanks to local and national government support.** The first is Changxin Memory Technologies. It was created in 2016 in the town of Hefei, Anhui province, with funding from Anhui's public investment fund. **Changxin has managed to acquire most of the IP portfolio of German firm Qimonda,** which was the European leader in memory chips before going bankrupt[48]. Changxin successfully recruited engineers from Taiwan, South Korea and Germany, including the former vice president of technology and predevelopment at Qimonda, who played a key role in developing Changxin's DRAM products. **In August 2020, Chinese business newspaper *Caixin* celebrated a landmark for Changxin: the company signed sales contracts for its new DRAM products and could supply up to 4% of the world's DRAM capacity – essentially on the Chinese domestic market – by the end of the year[49].** Changxin uses 19-nanometer technology, compared to 14 nanometers for the world's leading memory companies. At this stage of its growth, its main challenge today is to expand its customer base, moving upmarket.

45 KMPG, "新锐企业 50报告" (Report on 50 emerging companies), 2020, https://pdf.dfcfw.com/pdf/H3_AP202011061427101220_1.pdf?1604682090000.pdf
46 "Why China Welcomes SK hynix's Acquisition of Intel's NAND Flash Business", *Business Korea*, October 20, 2020, http://www.businesskorea.co.kr/news/articleView.html?idxno=53529
47 Source: IC Insights.
48 "ChangXin Emerging as China's First & Only DRAM Maker", *EETimes*, March 12, 2019, https://www.eetimes.com/changxin-emerging-as-chinas-first-only-dram-maker/
49 "In-Depth: China Creates New Memory Chip Champ, but Will Customers Come?", *Caixin*, August 17, 2020, https://www.caixinglobal.com/2020-08-17/in-depth-china-creates-new-memory-chip-champ-but-will-customers-come-101593672.html

The second Chinese national memory champion is Yangtze Memory Technology (YMTC). Based in Wuhan, it achieved the feat of maintaining its production at the heart of the lockdown that halted life in the metropolis at the height of the Covid-19 crisis in early 2020. YMTC benefits **from the support of Beijing conglomerate Tsinghua Unigroup, the state-owned company linked to the prestigious Tsinghua University and one of the Chinese government's most important tools to intervene financially in the semiconductor sector, through support for national initiatives and the acquisition of international assets.** In April 2020, YMTC announced that it had developed its own architecture for a 128-layer NAND flash memory integrated circuit, which is expected to be commercially available in 2021[50]. The performance of flash memory integrated circuits is enhanced by adding layers on top of each other in a limited space, with 128 layers being the most advanced generation. Thanks to this development, YMTC can consider entering computer market segments more advanced than USB sticks and memory cards, such as hard drives.

Other projects initiated by Tsinghua Unigroup in the memory sector have been much less successful. In Chengdu and Chongqing, two large investments were encountering serious delays at the end of 2020 because of human resources and issues of access to foreign technology, as leaked by an insider to Nikkei Asia[51].

The memory sector epitomizes **the strong tensions linked to Chinese intellectual property violations and technology theft.** Fujian Jinhua, a state-owned enterprise in the Fujian province, is accused by the U.S. Department of Justice of conspiring to steal Micron technology. The case follows a USD 23 billion bid by Tsinghua Unigroup to acquire Micron in 2015, which was dropped by the Chinese investor after clear signals that the Committee on Foreign Investment in the United States (CFIUS) would block the deal[52]. The technology theft took place through Taiwan's United Microelectronics Corp (UMC), employees of which shared their access with Tsinghua Unigroup and Fujian Jinhua. The conflict was settled in October 2020 when UMC agreed to pay a USD 60 million fine for industrial espionage to the U.S. Department of Justice[53].

50 "A Chinese firm made a memory chip that can compete with Samsung. What's next?", *Technode*, April 23, 2020, https://technode.com/2020/04/23/ymtc-memory-chip/

51 "Beijing-backed Tsinghua Unigroup's chip projects hit by delays", *Nikkei Asia*, November 30, 2020, https://asia.nikkei.com/Business/China-tech/Beijing-backed-Tsinghua-Unigroup-s-chip-projects-hit-by-delays

52 Department of Justice of the United States, "PRC State-Owned Company, Taiwan Company, and Three Individuals Charged With Economic Espionage", November 1, 2018, https://www.justice.gov/opa/pr/prc-state-owned-company-taiwan-company-and-three-individuals-charged-economic-espionage

53 "Taiwan's UMC to pay $60m fine to settle US trade secrets case", *Nikkei Asia*, October 29, 2020, https://asia.nikkei.com/Economy/Trade-war/Taiwan-s-UMC-to-pay-60m-fine-to-settle-US-trade-secrets-case

4. Assembly, packaging and testing

Assembly, packaging and testing is **the most internationally competitive segment of China's semiconductor industry –** three companies are in China's IC top ten, even if packaging and testing are at the downstream of the industry, with less added value than design and manufacturing. The growth of the segment has been driven by the demand of China's electronics manufacturing, the end-user of many integrated circuits. The proportion of imported integrated circuits reexported to third countries as electronic equipment has at times reached 75% and was at 55% in 2016, according to Crédit Suisse[54].

5. Material, equipment and software

China's complete industrial structure includes a domestic production of wafer and packaging material, and design and manufacturing equipment tools. China's upstream dependence on foreign suppliers has created vulnerabilities for both IC design and manufacturing which Chinese policies seek to reduce.

In most categories of the semiconductor materials industry, China's manufacturing capacity does not meet the need of its foundries. For silicon wafers, polishing liquid, photoresist technology, gases, platting solutions and sputtering target materials, the localization rate of production in China is between 5% and 20%[55].

But there are **two critical bottlenecks** that China needs to overcome to pass the 7-nanometer manufacturing hurdle: **a steady supply of EDA tools, and extreme ultraviolet lithography equipment.**

Dependence on EDA is a potentially fatal weakness for the Chinese semiconductor industry in case the US escalates the technology war. EDA tools are needed not only for the most advanced process, but for any manufacturing process. **The EDA industry is extremely concentrated – the six leaders account for 95% of the market.** In addition, their operations are increasingly moving into the cloud, which reinforces

54 Organisation for Economic Co-operation and Development, "Measuring distortions in international markets, The semiconductor value chain", November 21, 2019, http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=TAD/TC(2019)9/FINAL&docLanguage=En

55 Litho World, "Current Status of the Integrated Circuit Industry in China – IC Manufacturing Industry", *Journal of Microelectronic Manufacturing*, vol. 2, issue 2, June 2019, http://www.jommpublish.org/p/issue/369/

their control over the IC designers[56]. By contrast, China's EDA companies accounted for only 10% of its USD 500 million domestic market in 2018[57]. China's leader by far, Empyrean Software, was founded in 2009 as a subsidiary of China Electronics Corporation. It is estimated that Empyrean Software's capacity is limited to about one-third of the EDA needs of the Chinese integrated circuit industry. Asked if Empyrean could replace foreign suppliers as a source for Huawei, a representative for the company was quoted saying that "it would be like we sold cars, but Huawei came in and asked us to build airplanes or even rockets for them"[58]. That Empyrean's customers are overwhelmingly domestic is a problem. As the leading IC foundries work hand in hand with the leading EDA developers, **Chinese EDA developers find themselves excluded from the virtuous circle of innovation by operating mainly inside their domestic ecosystem.** This is a major bottleneck for the upgrade of the whole Chinese industry.

Advanced lithography is another chokepoint. China's leading company, Shanghai Micro Electronics Equipment, produces 90 nm lithography and is scheduled to deliver its first 28 nm lithography machines in 2021/2022, but this is far behind state-of-the-art technology. In an academic paper published by the Chinese Academy of Sciences, four authors from HiSilicon note that "EUV lithography has achieved great progress since 2015, most of breakthroughs take place after the formation of EUV industry alliances among big player like ASML, Intel, TSMC and Samsung. As the only EUVL scanner commercial provider, ASML is going to sell over 30 EUV modules in 2019. The market is ramping up and this revolutionary technology will lead the industry to the next decade"[59]. Even if two institutes of the Chinese Academy of Sciences have research programs on EUV technology, **Chinese contract foundries will not be able to develop 7 nm nodes if export controls prevent ASML from selling them advanced EUV machines.**

The importance of Arm China for the local integrated circuit ecosystem illustrates China's dependence on foreign intellectual property – Arm's interfaces are very well integrated in the EDA tools of the market leaders and dominate IC design. Arm China was established in 2018 as a joint venture in which the parent company in the UK,

56 See for example Cadence's cloud hosted design solutions, https://www.cadence.com/ko_KR/home/solutions/cadence-cloud/cloud-hosted-design-solution.html
57 Litho World, "Current Status of the Integrated Circuit Industry in China – EDA Industry Review", *Journal of Microelectronic Manufacturing*, vol. 2, issue 3, September 2019, http://www.jommpublish.org/p/36/
58 Saif M. Khan, "US Semiconductor export to China, current policies and trends", Center for Security and Emerging Technology, Georgetown University, October 2020, https://cset.georgetown.edu/wp-content/uploads/U.S.-Semiconductor-Exports-to-China-Current-Policies-and-Trends.pdf
59 Nan Fu, Yanxiang Liu, Xiaolong Ma, Zanfeng Chen, "EUV Lithography: State-of-the-Art Review", *Journal of Microelectronic Manufacturing*, vol. 2, no. 2, June 2019, http://www.jommpublish.org/p/29/

Arm Ltd, only holds a minority stake of 49%, while a consortium of Chinese investors holds 51%. **Arm's intellectual property is essential to most IC designers. It is to be found in the most advanced digital applications developed by Broadcom, Qualcomm, Nvidia, MediaTek, Samsung, etc.** The focus of Arm's innovation is processor cores for AI in the cloud, but today Arm's architecture is dominant in most handset and IoT devices. Under the Joint Venture agreement, Arm China is entitled to full access to its parent company's intellectual property, and it is also the exclusive channel for licensing Arm's intellectual property in China[60]. However, Arm China remains a "sales unit" with only three self-developed patents, against more than 1,000 for its British parent[61]. In that light, Chinese regulators will face a major policy decision when examining Nvidia's bid to purchase Arm from Softbank, for an amount of around USD 40 billion. Given the importance of access to Arm's intellectual property for IC design to the Chinese industry, greenlighting US control over the company carries risks from a Chinese perspective[62]. The Chinese industry has been discussing open-source alternatives to Arm architecture for years. Arm's architecture is open for many interfaces, and the open-source space is increasing, **but most industry sources see no credible sign that open source constitutes a comprehensive alternative in case Arm architecture is targeted by US restrictions.**

6. Chokepoints and foreign dependence

In short, Chinese companies cover the entire spectrum of semiconductor production but **depend on foreign technologies, equipment, and intellectual property at all stages of the production process, and not only for the most advanced processes.** Given the exposure of the Chinese semiconductor industry to US sanctions, there has been since 2019 a stronger push by the government and companies to develop alternative domestic sources of supplies for equipment, chemicals and software. For example, Yangtze Memory has set the goal of sourcing 70% of its equipment from domestic suppliers, against 30% in 2019.

60 "How SoftBank's sale of Arm China sowed the seeds of discord", *Nikkei Asia*, June 16, 2020, https://asia.nikkei.com/Business/China-tech/How-SoftBank-s-sale-of-Arm-China-sowed-the-seeds-of-discord
61 "In Depth: Self-Dealing Dispute Lies at Heart of Arm Ltd.'s Dustup with China CEO", *Caixin*, June 29, 2020, https://www.caixinglobal.com/2020-06-29/in-depth-self-dealing-dispute-lies-at-heart-of-arm-ltds-dustup-with-china-ceo-101573141.html
62 "In Depth: China Plays Kingmaker in Nvidia's $40 Billion Bid for Arm", *Caixin*, September 23, 2020, https://www.caixinglobal.com/2020-09-23/in-depth-china-plays-kingmaker-in-nvidias-40-billion-bid-for-arm-101608754.html

But China's vulnerabilities remain easily exploitable. As underscored by a scholar from the Chinese Academy of Sciences: "Obviously, the most prominent shortcoming restricting China's technological innovation and economic development is that the core technology is not in our own hands and we are facing a serious bottleneck problem. **Even if we benefit from the global division of labor thanks to our comparative advantages, we still need to have control over core technologies.** It is a fact that in the fierce international competition, core technology cannot be obtained through market exchange"[63]. Indeed, access to foreign technology will remain complicated due to transfer restrictions that have considerably tightened as a result of the Trump administration's pushback against China's rise as a technological powerhouse, aggravating China's bottleneck problem.

63 Sui Jigang, "把科技自立自强作为国家发展的战略支撑怎么做" (Science and technology self-reliance as the key pillar of our national development strategy: how to get there?), *Liaowang*, no. 44, November 2020, http://lw.xinhuanet.com/2020-11/02/c_139485240.htm

II

THE UNITED STATES ON THE OFFENSIVE

Under the Trump administration, the US has gradually identified semiconductors as a powerful lever in its competition against China. This came almost empirically, **as part of the intensification of the American campaign against Huawei's 5G infrastructure offer to the world.** The initial focus was a public diplomacy campaign pointing to the security risks of choosing Huawei. It is only in a second stage **that the US created a barrier system preventing Huawei and its affiliate companies – in particular HiSilicon – from accessing foreign semiconductor technology.** The campaign had a strong effect, putting in question Huawei's capacity to deliver and to maintain 5G networks, and hitting Huawei's smartphone offer hard. Towards the end of President Trump's mandate, **the US action expanded to semiconductor companies serving military end-users,** as part of an effort to tame the flow of technology transfers contributing to the modernization of the China's People's Liberation Army. At the same time, a review of export control and foreign investment regulations are also leading to greater restrictions on China's access to US semiconductor technology, and to semiconductors produced in third countries given the extraterritorial practices of the United States. And finally, the action taken by the Trump administration also comes in reaction to a practice of theft of US intellectual property by Chinese actors, which has particularly affected the semiconductor industry, from Qualcomm to Micron.

1. The campaign against Huawei's access to foreign semiconductor technology

In 2019, Huawei held 29% of the world's telecom infrastructure market (3G and 4G especially). The equipment provider was on its way to increase this global market share as telecommunications companies and governments across the world were taking decisions regarding the construction of 5G infrastructure.

There is no question that the construction of **the 5G generation of networks by Huawei between 2020 and 2025 would provide China with a considerable strategic resource in terms of intelligence collection and political influence in the countries that have picked the Chinese equipment.** 5G will transform many industries, public services and even aspects of national defense[64]. The ubiquity of data connection means that **the protection of critical infrastructure from risks of intrusion, extraction, and sabotage must be taken with a greater sense of urgency than those related to previous generations of telecommunications networks.** What state would dare to take a strong stance against China with its public services exposed to paralysis? Such a scenario of China neutralizing American allies in the heat of a Sino-American confrontation is an important element of the big strategic picture, beyond pure business and cost considerations.

The American offensive took place in three stages. It was mainly led by the Department of Commerce's Bureau for Industry and Security (BIS). BIS's mission statement is to “advance U.S. national security, foreign policy, and economic objectives by ensuring an effective export control and treaty compliance system and promoting continued U.S. strategic technology leadership”. In May 2019, BIS added Huawei Technology and some of its affiliated companies to its “Entity List”. This designation requires all American companies doing business with Huawei, plus foreign companies whose products include a certain value percentage of American components, to obtain an export license from the US administration. The decision was motivated by Huawei's alleged violations of sanctions against Iran observed by the Department of Justice. **But immediately following this decision, the Department of Commerce created an exemptions system through temporary general 90-day licenses, which would be continuously renewed until August 2020[65].** In practice, the designation of Huawei and affiliates on the entity list was therefore first and foremost a threat, but not only. Export licenses for new types of exports were not easily issued, and Huawei lost access to updates to the Android operating system[66]. For Chinese customers of new Huawei phones, the loss of access to Google Mobile Services is not a major issue as the suite is blocked anyway. For the brand's international customers, it is a major inconvenience. **But Huawei could work with an open-source version and had to speed up the development of its own operating system and catalog of applications.**

Therefore overall, the initial blow was harsh but not excessively brutal. At the beginning of 2020, the key question was about future uncertainties: **would the temporary exemption system end at some point? It did.** The situation would gradually worsen for Huawei during the summer of 2020, with two radical decisions expanding the reach of the US Export Administration Regulations (EAR) that target Huawei's access

64 Institut Montaigne, *"5G in Europe, Time to Change Gear"*, Policy Paper, May 2019, https://www.institutmontaigne.org/en/publications/5g-europe-time-change-gear-part-1

65 Office of Public Affairs, Bureau of Industry and Security “Huawei Entity List and Temporary General License Frequently Asked Questions (FAQs)”, Update, May 18, 2020, https://www.bis.doc.gov/index.php/documents/pdfs/2447-huawei-entity-listing-faqs/file

66 “Huawei's Android loss, how it affects you”, *BBC*, May 20, 2019, https://www.bbc.com/news/technology-48334739

to semiconductor technology. In May 2020, BIS announced that export licenses would be required to sell semiconductor design and chipsets produced using software, technology and equipment that includes US intellectual property[67]. In practice, this meant that HiSilicon could no longer have TSMC manufacturing its high-end smartphone processors, leaving it with no alternative. **In July 2020, TSMC announced compliance with the US regulations, making clear that it would no longer accept new orders from Huawei and its affiliates[68].**

A subsequent BIS decision in August 2020 would shut off any remaining loopholes for Huawei[69]. In addition to announcing the end of the general temporary exemptions system, the decision adopted a catch-all approach to all Huawei affiliates and subsidiaries designated on the entity list, making clear that the EAR license system applies when they “are a party to the transaction, such as by acting as purchaser, intermediate consignee, ultimate consignee, or end-user”. **In practice, the new regulation was extending control to all transactions where the product includes US intellectual property when the end-user is Huawei and its affiliates.**

The US action has exposed the extreme vulnerability of Huawei's 5G infrastructure offer. The core chipset of Huawei's 5G base stations was produced by TSMC using 7 nanometer technology. Shipments have ended and Huawei has announced that it had enough stocks to continue production until the end of 2020[70]. To build its future base stations, Huawei needs access to specific integrated circuits, called field-programmable gate arrays (FPGAs), which enable updating the internal communication of the base station and software control. Huawei used Xilinx's FPGA for the possibility to reprogram 5G base stations even after the base station is already installed in a tower[71]. **Huawei has built up stocks of FPGAs thanks to temporary general licenses, but access is no longer possible[72].** Huawei's alternative solution is to replace FPGAs with application-specific integrated circuits, which fall under US regulations but could be manufactured domestically.

67 Office of Public Affairs, Bureau of Industry and Security, “Commerce Addresses Huawei's Efforts to Undermine Entity List, Restricts Products Designed and Produced with U.S. Technologies”, May 15, 2020, https://www.commerce.gov/news/press-releases/2020/05/commerce-addresses-huaweis-efforts-undermine-entity-list-restricts

68 “TSMC halts new Huawei orders after US tightens restrictions”, *Nikkei Asia*, May 18, 2020, https://asia.nikkei.com/Spotlight/Huawei-crackdown/TSMC-halts-new-Huawei-orders-after-US-tightens-restrictions

69 Office of Public Affairs, Bureau of Industry and Security, “Commerce Department Further Restricts Huawei Access to U.S. Technology and Adds Another 38 Affiliates to the Entity List”, August 17, 2020, https://www.commerce.gov/news/press-releases/2020/08/commerce-department-further-restricts-huawei-access-us-technology-and

70 “Huawei has enough telecom chips in stock to last years: Sources”, *The Elec*, August 19, 2020, http://www.thelec.net/news/articleView.html?idxno=1399

71 “Xilinx Envisions its Future Without Huawei”, *EET Asia*, October 29, 2019, https://www.eetasia.com/xilinx-prepares-for-a-future-without-huawei/

72 “Huawei builds up 2-year reserve of “most important” US chips”, *Nikkei Asia*, May 28, 2020, https://asia.nikkei.com/Spotlight/Huawei-crackdown/Huawei-builds-up-2-year-reserve-of-most-important-US-chips

In addition, the regulations have also raised severe doubts regarding **Huawei's ability to remain competitive in the global smartphone market, once its stocks run dry.** Richard Yu, one of Huawei's executive directors, has already announced that from September 2020, the HiSilicon subsidiary would no longer be able to produce the Kirin processors that equip the brand's smartphones because of these new restrictions. At stake is **Huawei's ability to stay in the race of high-end 5G smartphones and compete with Apple and Samsung on the one hand, and Chinese growing champions like Oppo and Xiaomi on the other hand.**

As a result, while the American diplomatic campaign initially struggled to convince its European allies and friends, countries like Sweden and the United Kingdom decided in the end to phase out Huawei from their telecommunication networks, arguing that the US sanctions regime created too many uncertainties regarding Huawei's capacity to build and maintain a network[73].

In the end, export control rules depend on their enforcement. Adopting a strict licensing system does not preclude the final granting of licenses, even if requests are examined under a presumption of denial. US Secretary of Commerce Wilbur Ross mentioned "aggressive implementation" of these rules[74]. Under the Trump administration, some licenses have been granted to US and foreign companies. **While this is not official US policy, in practice at the beginning of 2021, Huawei seems to be allowed enough access to foreign technology to maintain its 4G networks[75].** Even with the system of temporary general licenses and the practice of granting some licenses, these decisions have had a cost for US companies. Broadcom, 5% of the turnover of which depended on Huawei, estimates the loss at USD 2 billion in 2019. Will the Biden administration allow the flow of technology to save Huawei's smartphone business while maintaining maximum pressure on the telecommunication equipment side? **How the Biden administration will approach the matter is uncertain at the time of writing.**

73 Press Release, "Huawei to be removed from UK 5G networks by 2027", gov.uk, July 14, 2020, https://www.gov.uk/government/news/huawei-to-be-removed-from-uk-5g-networks-by-2027. Swedish Post and Telecom Authority, "Four companies approved for participation in the 3.5 GHz and 2.3 GHz auctions", press release, October 20, 2020, https://www.pts.se/en/news/press-releases/2020/four-companies-approved-for-participation-in-the-3.5-ghz-and-2.3-ghz-auctions/

74 "Trump administration sees no loophole in new Huawei curb", *Reuters*, June 23, 2020, https://www.reuters.com/article/us-usa-china-huawei-tech-idUSKBN23U2K8

75 "Intel gets U.S. licences to supply some products to Huawei", *Reuters*, September 22, 2020, https://www.reuters.com/article/intel-huawei-idUSKCN26D0I3

2. Further action against China's semiconductor industry/ the military end-user issue

Under the Trump administration, three complementary actions have been taken. They focus on China's military end-users and on companies involved in human rights violations. Even though no US official has stated clearly that this was the goal of the US policy, **acts suggest that they aim at preventing the Chinese IC manufacturing industry from mastering the capacity to process the 7 nm node.** And in addition to targeted action, the ongoing review of US export control, and the inclusion of "emerging and foundational technologies" in its scope, will place additional restrictions on transfers of semiconductors, and affect US allies in Europe and in East Asia, as well as Taiwan. It is important to note that action is not limited to export control regulations. Emerging and foundational technologies will be subject to increased export control, but they also qualify as "critical technologies" under the Foreign Investment Risk Review Modernization Act (FIRRMA), which broadens the scope of action of the Committee on Foreign Investment in the United States (CFIUS) and allows expanded jurisdiction to review foreign investment transactions that might lead to foreign access to US critical technology. This strengthening of foreign investment screening in the United States is relevant for the semiconductor sector, especially **because broadened jurisdiction now allows measures to be taken to impose conditions (or reject) on transactions based on non-controlling stakes that allow access to critical information or governance rights[76].**

Wassenaar and multilateral export control

The Wassenaar Arrangement, the first global multilateral arrangement on export controls for conventional weapons and sensitive dual-use goods and technologies, has emerged as an important theater in the US-China technology competition. The 42 Member States of the Wassenaar Arrangement **regularly produce an updated list of technologies on which signatories impose export controls in their national jurisdiction – at the end of 2020, the list contained more than 150 semiconductor end-products** and more than 20 types of semiconductor manufacturing equipment[77]. Wassenaar controls focus on military end-uses of the technology acquired.

76 US Department of Treasury, "Summary of the Foreign Investment Risk Review Modernization Act of 2018", https://home.treasury.gov/system/files/206/Summary-of-FIRRMA.pdf

77 Saif M. Khan, "US Semiconductor export to China, current policies and trends", 2020, op. cit.

In early 2019, the US government pressed the Dutch government to deny ASML an export license for selling an EUV machine to SMIC. EUV technology is listed under the arrangement as part of controlled lithography[78]. The rationale behind the listing is **that EUV technology can have a major upgrading effect on the arms industry of a state.** In early 2021, the export license had not been formally denied, but had been examined for more than a year.

The transfer of EUV technology to China is controlled against possible military end-uses. **But the issue suggests an intention to slow down China's IC manufacturing upgrade to the 7 nm generation, as EUV is a chokepoint technology to pass that threshold.** If 7 nm is key to many products of the ongoing digital transformation, it can also increase the general science and technology (S&T) level of an arms industry, by opening new avenues for military innovation. This developing story raises important policy questions **regarding the scope of Dutch and European export controls for semiconductor technology,** and on the extent to which **a clear European doctrine is specifically needed to examine transfers of semiconductor technology to China.**

Military end-users

The US government controls the export of semiconductors as dual-use technology through lists of items and increasingly list of end-users – this second modus operandi has been on the rise under the Trump administration. Historically for the semiconductor sector, list-based controls have mostly resulted in granting export licenses, while controls focusing on military end-users are more stringent[79].

The Trump administration took three steps to increase controls on military end-users. In June 2020, new export control rules entered into force, with important consequences for transfers of semiconductor technology. **They essentially created a catch-all system to control technology transfers to China, Russia and Venezuela.** Enacted by BIS, the new rules expand the scope of the Export Administration Regulations to create a system of mandatory license requirements on exports, reexports, and transfers of items intended for military end-use or military end-users in the three

78 Wassenaar Arrangement on Export Controls for Conventional Arms and Dual-Use Goods and Technologies, "List of Dual-Use Goods and Technologies and Munitions List", October 2019, https://www.wassenaar.org/app/uploads/2019/12/WA-DOC-19-PUB-002-Public-Docs-Vol-II-2019-List-of-DU-Goods-and-Technologies-and-Munitions-List-Dec-19.pdf

79 Saif M. Khan, "US Semiconductor export to China, current policies and trends", 2020, op. cit.

targeted countries[80]. The rules have extraterritorial jurisdiction. This causes practical problems to companies operating in the high-tech space with exports to China. **Items that previously did not fall in the control category could be retrospectively qualified by the US Commerce Department as a transfer to a military end-user.**

In June 2020, the US Department of Defense released a list of **"Chinese communist military companies", including Huawei and Hikvision, and many large public arms conglomerates[81].** An August update included China Electronics Corporation (CEC), and SMIC was added to the list in December 2020. In addition to targeting end-users of semiconductor technology, **the list targets China's semiconductor industry as a whole.** This approach is an adjustment of export controls to the specific nature of China's state capitalism in combination with Xi Jinping's strong push to accelerate civil-military integration, with the primary aim of modernizing the People's Liberation Army. The list provides a basis for US executive action in the area of export controls but also of financial transactions. **Whether the Biden administration will make further use of this instrument is unclear,** as export control experts from the Democratic camp have criticized the designation approach and expressed support for controls centered on specific technologies[82].

US controls over transfers of semiconductor technology to China will be further strengthened when a legal definition of "emerging and foundational technologies" is finally adopted. **Emerging technology poses a challenge for regulators. How to update control lists when innovation is fast?** How to adapt public controls when innovators have a strong incentive to seek private capital to bring their findings to a mature stage? The adoption of a legal definition has important implications for the semiconductor industry.

The process started as part of the Export Control Reform Act of 2018, which directed the Bureau of Industry and Security to produce such a list through an interagency process. **The aim is to cover technologies that are not yet covered by multilateral control arrangements, and in particular Wassenaar (raising the question of whether a specific multilateral arrangement is needed for such**

80 Bureau of Industry and Security, "Expansion of Export, Reexport, and Transfer (in-Country) Controls for Military End Use or Military End Users in the People's Republic of China, Russia, or Venezuela", April 28, 2020, https://www.federalregister.gov/documents/2020/04/28/2020-07241/expansion-of-export-reexport-and-transfer-in-country-controls-for-military-end-use-or-military-end

81 For the initial list: https://media.defense.gov/2020/Aug/28/2002486659/-1/-1/1/LINK_2_1237_TRANCHE_1_QUALIFIYING_ENTITIES.PDF

82 Online transatlantic roundtable discussion with export control experts, December 8-9, 2020.

technologies). A first proposal included 14 categories, of which many are directly related to semiconductors (surveillance technology, advanced computing technology, data analysis technology, quantum information and sensing), if not semiconductor per se (AI chipsets and microprocessor technology)[83]. In August 2020, the process was revised. Instead of listing categories, the focus is **now on the criteria for identifying and describing foundational technologies.** The main difference is a recognition that they "could include items that are currently subject to control for military end-use or military end-user (…) including semiconductor manufacturing equipment and associated software tools, lasers, sensors, and underwater systems"[84]. The final outcome of the process will be the creation of new categories under the Export Administration Regulations, and their integration into the scope of the US foreign investment screening mechanism.

Control on end-users involved in human rights violations

Eight Chinese technology firms were added to the Bureau of Industry and Security's Entity List in September 2019 for their involvement in human rights violations related to China's campaign of arbitrary detention against Uighurs, Kazakhs, and other Muslim minorities in the Xinjiang region. **Among these eight companies are well-known names such as Hikvision, a specialist in surveillance cameras, and Megvii, which develops image recognition solutions.** Megvii was forced to find alternatives to Nvidia and Hikvision to Intel[85]. But unlike Huawei, they do not need the most advanced generation of semiconductors and have national alternatives and thus are less vulnerable to sanctions.

83 Bureau of Industry and Security, "Review of Controls for Certain Emerging Technologies", November 19, 2018, https://beta.regulations.gov/document/BIS-2018-0024-0001
84 Bureau of Industry and Security, "Identification and Review of Controls for Certain Foundational Technologies", August 27, 2020, https://www.federalregister.gov/documents/2020/08/27/2020-18910/identification-and-review-of-controls-for-certain-foundational-technologies
85 "U.S. Tech Companies Prop Up China's Vast Surveillance Network", *Wall Street Journal*, November 26, 2019, https://www.wsj.com/articles/u-s-tech-companies-prop-up-chinas-vast-surveillance-network-11574786846

IV

BEYOND CATCH-UP: CHINA'S SEMICONDUCTOR INDUSTRIAL POLICY

The American offensive against its semiconductor industry has left China with **no other choice than accelerating its pre-existing plans for greater self-reliance, with a sense of urgency.** China has capital, the scale of its market, strengths in S&T and a diverse industrial ecosystem. But China's top-down, state-led investment-driven model in the semiconductor industry faces three major shortcomings: **waste and a suboptimal allocation of resources; foreign obstacles in the form of new barriers to technology transfers; and an inability to solve the industry's human resources problem in the medium term.** The combination of these three factors suggests that China is unlikely to reach its targets and will use all the resources at its disposal to circumvent chokepoints in access to foreign technology, from innovation efforts at home to overseas acquisition when possible.

1. Strategic plans and policy incentives

China has had many national plans for its semiconductor industry. But the Chinese government identified semiconductors as a priority as early as 1956. The first 10-year plan for technological and scientific development led to the establishment of university research programs and the first national industrial facilities. In the 1960s, **China's technological level in the sector had nothing to envy to that of Japan, South Korea, and Taiwan[86].** It only started accumulating a considerable technology gap in the 1970s and 1980s, when offshoring intensified in non-communist East Asia, coupled with national policies supporting the rise of a microelectronics industry. The 1990s saw a policy effort to acquire foreign technologies through encouraging joint ventures to move production into China. This policy succeeded in attracting Philips, NEC, and Lucent. The most ambitious initiative, "Project 909", aimed at the development of memory chips by Shanghai Hua Hong NEC Electronics Co. Ltd., a joined

86 John VerWey, "Chinese Semiconductor Industrial Policy: Past and Present", *Journal of International Commerce and Economics*, US International Trade Commission, July 2019.

venture formed by China's Hua Hong and Japan's NEC. However, the Japanese firm was extremely cautious to avoid forced technology transfers[87]. Advanced IC manufacturing was listed as a priority in China's fifteen-years plan, the Medium and Long-Term Development Plan for Science and Technology (2006-2020) as part of 16 industrial sectors, including core electronic components (such as chip design and equipment)[88].

The goal of becoming a global leader was formulated later. It appeared for the first time in the State Council's 2014 National Integrated Circuit Industry Development Guidelines[89]. This reformulation of the country's ambitions with language stressing leadership and innovation is consistent with the general policy priorities set under the leadership of Xi Jinping.

87 Ibidem.
88 State Council, "The National Medium-and Long-Term Program for Science and Technology Development (2006-2020); An Outline", https://www.itu.int/en/ITU-D/Cybersecurity/Documents/National_Strategies_Repository/China_2006.pdf
89 Dieter Ernst, "From Catching Up to Forging Ahead, China's Policies for Semiconductors", *East-West Center Special Study*, September 8, 2015, https://www.eastwestcenter.org/publications/catching-forging-ahead-chinas-policies-semiconductors

Table 5: Strategic plans and policy guidelines for the semiconductor industry (2014-2020)

January 2017	Plan & Policy	Issuing Authority
2014	National Integrated Circuit Industry Development Guidelines 《国家集成电路产业发展推进纲要》	State Council
May 2015	Made in China 2025 《中国制造2025》	State Council
May 2016	Notice on issues related to preferential income tax policies for software and integrated circuits《关于软件和集成电路企业所得税优惠政策有关问题的通知》	State Administration of Taxation
July 2016	Outline of National Information Development Strategy《国家信息发展战略纲要》	State Council
November 2016	"13th Five-Year" National Strategic Emerging Industry Development Plan《"十三五"国家战略性新兴产业发展规划》	State Council
January 2017	List of key products and services in strategic emerging industries《战略性新兴产业重点产品和服务指导目录》	National Development and Reform Commission
March 2018	Announcement on issues concerning income tax policy for integrated circuit manufacturers《关于集成电路生产企业有关所得税政策问题的通知》	State Administration of Taxation
May 2019	Announcement on the corporate income tax policy for integrated circuit design and software industry《关于集成电路设计和软件产业企业所得税政策的公告》	Ministry of Finance
August 2020	Policies of Promoting High-quality Development of Integrated Circuit Industry and Software Industry《新时期促进集成电路产业级软件产业高质量发展的若干》	State Council
December 2020	Announcement on the corporate income tax policy for promoting the high-quality development of the integrated circuit and the software industries《关于促进集成电路产业和软件产业高质量发展企业所得税政策的公告》	Ministry of Finance, State Administration of Taxation, NDRC, Ministry of Industry and Information Technology

Made in China 2025 is the country's best-known plan: **it has led Europe, the United States, and Japan to finally express concerns over the technological ambitions of a Chinese state capitalism that is not afraid to resort to predatory practices when it comes to accessing foreign technologies[90].** Adopted in 2015, the plan reads above all as a declaration of objectives for world leadership in ten sectors with high added value: information technology, robotics, aerospace, advanced materials, shipbuilding, etc. All these sectors require control of semiconductors. The plan sets

90 For example: "EU business group slams Beijing's "Made in China" plan", *Reuters*, March 7, 2017, https://www.reuters.com/article/us-china-eu-business-idUSKBN16E0A2

the objective of a national production of 40% of Chinese consumption by 2020 and 70% by 2025[91]. Again at the 5th plenum of the 19th Central Committee, the design and the manufacturing of semiconductor is reaffirmed as a priority[92]. **Integrated circuits are mentioned as a priority as part of "strengthening the nation's S&T power"** (强化国家战略科技力量)[93].

China's current effort to move from catching up to leadership and near self-reliance in the most advanced foundry processes is supported by **an extremely well-funded industrial policy, which includes public R&D funding, direct subsidies, favorable IP regimes and tax regimes.** Today, two policy packages matter the most. First, in 2011, the State Council adopted *Several Policies for Further Encouraging the Development of the Software Industry and Integrated Circuit Industry*[94]. The measure includes exemptions of enterprise income tax for companies that have been operating for more than 15 years and manufacture 65 nm semiconductor. It also creates a special regime for IC design and software companies: those identified by the State (NDRC and the Ministry of Industry and Information Technology) are exempted from enterprise income tax from the first to the fifth year, and pay enterprise income tax at the reduced tax rate of 10% for consecutive years.

In August 2020, this package of measures was updated when the Chinese government adopted the *Policies of Promoting High-quality Development of Integrated Circuit Industry and Software Industry*[95]. The policy includes tax breaks, direct funding, and support for research and talent development measures, as well as tariff exemptions for the import of equipment needed for semiconductor production, which complement an already highly incentivizing package. Similar to the 2011 measures, a corporate income tax exemption system seeks to favor the most technologically-advanced companies – the most important exemptions are reserved for companies producing or using integrated circuits from the 28-nanometer generation upwards[96].

91 Full text of the plan: State Council 2015 (25), "国务院关于印发《中国制造2025》的通知" (Announcement of the State Council regarding the issuing of Made in China 2025), May 8, 2015, http://www.gov.cn/zhengce/content/2015-05/19/content_9784.htm
92 "China's latest five-year plan girds for battle", *Reuters*, November 2, 2020, https://www.reuters.com/article/us-china-politics-breakingviews/breakingviews-chinas-latest-five-year-plan-girds-for-battle-idINKBN27I09B
93 "中共中央关于制定国民经济和社会发展第十四个五年规划和二〇三五年远景目标的建议" (Proposal of the Central Committee of the Chinese Communist Party on Drawing Up the 14th Five-Year Plan for National Economic and Social Development and Long-Range Objectives for 2030), *Xinhua*, November 3, 2020, http://www.gov.cn/zhengce/2020-11/03/content_5556991.htm
94 State Council Circular No. 4, 2011 (Several Policies for Further Encouraging the Development of the Software Industry and Integrated Circuit Industry), http://www.lawinfochina.com/display.aspx?id=33683&lib=law
95 State Council Circular no. 8, 2020, "国务院关于印发新时期促进集成电路产业和软件产业高质量发展若干政策的通知" (Several Policies for Promoting High-quality Development of Integrated Circuit Industry and Software Industry), July 27, 2020, http://www.gov.cn/zhengce/content/2020-08/04/content_5532370.htm
96 Zoey Zhang, "China's Incentives for Integrated Circuit, Software Enterprises", China Briefing, August 6, 2020, https://www.china-briefing.com/news/china-incentives-integrated-circuit-software-enterprises-us-china-technology-decoupling/

These measures were refined in a package released in December 2020[97]. The tax exemption calibrated against the technology generation is an incentive for IC manufacturers to upgrade step by step, without rushing to leapfrog. The 28 nm and 65 nm nodes are mature technologies that are widely used in wireless networks, image sensors and power management chips. This suggests support for the growth of the Internet of Things industry.

In addition to these specific policy measures, the growth of China's semiconductor industry will benefit from other policy supports aiming at "strategic emerging industries", which have a very strong focus on information technology, biotech, high-end manufacturing and autonomous vehicles[98].

2. An abundance of capital

Many industry leaders estimate that by 2020, **the total public funding of the semiconductor industry at the national and provincial level in China amounts to USD 150 billion.** Despite the astronomical amounts needed to build the most advanced fabs, capital intensity is not China's main problem.

The China Integrated Circuit Industry Investment Fund (CICIIF), also known as the Big Fund (大基金), is a direct product of the State Council's 2014 guidelines for the industry. The Big Fund was established in 2014 under the guidance of the Ministry of Industry and Information Technology, with co-leadership provided by the Ministry of Finance, China Development Bank and Huaxin Investment (a private equity firm). The Big Fund raised USD 51 billion in 2015 and USD 29 billion in 2019, mainly from state-owned players – investors include central SOEs such as China Telecom, China Unicom and China Electronics Corporation and provincial SOEs such as Shanghai Guosheng. In 2018, its three largest investors were the Ministry of Finance (36.7%), the China Development Bank (22.3%), and state-owned enterprise China Tobacco (11.1%)[99].

97 Ministry of Finance, State Administration of Taxation, NDRC, Ministry of Industry and Information Technology, Circular no. 45, 2020, "关于促进集成电路产业和软件产业高质量发展企业所得税政策的公告" (Announcement on the corporate income tax policy for promoting the high-quality development of the integrated circuit and the software industries), http://www.gov.cn/zhengce/zhengceku/2020-12/17/content_5570401.htm
98 National Development and Reform Commission, "关于扩大战略性新兴产业投资 培育壮大新增长点增长极的指导意见" (Guiding Opinions on Expanding Investment in Strategic Emerging Industries and Cultivating Strengthened New Growth Points and Growth Poles), Document no. 1409, 2020. *DigiChina*, a project based at the Stanford University Cyber Policy Center, has produced an English translation, https://www.newamerica.org/cybersecurity-initiative/digichina/blog/new-chinese-ambitions-strategic-emerging-industries-translated/
99 John VerWey, "Chinese Semiconductor Industrial Policy: Past and Present", *Journal of International Commerce and Economics*, US International Trade Commission, July 2019.

Starting in 2019, **the second fundraising phase was open to local funds. As a result, it attracted capital from the three main high-technology belts in China,** the Yangtze region around Shanghai, the Greater Beijing area and the Sichuan/Hubei area, with for example participation from the Chongqing strategic emerging industry equity investment fund[100].

During phase 1 of the investment period, the Big Fund has invested in 70 projects according to public information – it does not have its own website. The strategy of the fund is **to invest in the key companies in each segment of the industry, seeking a balance between supporting their technological breakthroughs and ensuring safe returns[101].** By one estimate, it concentrated on IC Manufacturing, which represents 47.8% of its investment (CNY 50 billion), while IC design amounts to 19.7%, assembly and testing 11%, and only 1.2% for equipment and 1.4% for material[102]. By another count, provided by TF Securities, the repartition was 67% for IC manufacturing, 17% for design, 10% for assembly and testing and 6% for equipment, material and software[103]. About 30% of its projects are public equity investment, while 48% are private equity investment in non-listed companies. The rest is support for mergers and acquisitions, and equity participation in sub-funds at the local level, such as Beijing IC Manufacturing and Shanghai IC Manufacturing funds[104]. **As of 2020, as the second phase of investment has started, the Big Fund starts responding to a changed environment and shows signs of diverting its focus away from IC manufacturing to equipment and software[105].**

The CICIIF is complemented by other funds that ensure the sector is flush with public cash and allow for international acquisitions. The 2020 policy incentives encourage provincial and local governments to play their full role. **This is already reflected in the Chinese semiconductor industrial landscape, where many groups are rooted in a provincial or municipal ecosystem, in order to facilitate their access to research and development but also to local sources of funding.**

100 Luffy Liu, "China's 'Big Fund' Phase II Aims at IC Self-Sufficiency", *EETimes*, October 30, 2019, https://www.eetimes.com/chinas-big-fund-phase-ii-aims-at-ic-self-sufficiency/
101 "史上最全集成电路大基金投资路线:70芯片项目,4大投资逻辑", *Zhineng Neican*, May 13, 2019 (The investment approach of the most comprehensive integrated circuit fund in history: 70 chip projects, 4 major logics), https://zhuanlan.zhihu.com/p/65550750
102 "广发证券:国家集成电路产业基金一期投资解析" (GF Securities: National Integrated Circuit Industry Fund Phase I Investment Analysis), *Xinlang Caijing*, March 13, 2019, https://finance.sina.com.cn/stock/hyyj/2019-03-13/doc-ihsxncvh2157328.shtml
103 TS Securities, "半导体 :砥砺前行，助力产业——集成电路产业基金投资布局" (Semiconductors, Forge ahead and support the industry : the layout of the Integrated Circuit Investment Fund), http://data.eastmoney.com/report/zw_industry.jshtml?encodeUrl=CoQVNtOv2xRu4mwXGEFmgGeDpMA+o1moWc2A1ppC0v4=
104 Ibidem.
105 Source: interviews with senior industry analysts, Taipei, September 2020.

Tsinghua Unigroup, a key player in the semiconductor industry, has played an important role in mobilizing provincial resources to support specific projects, such as DRAM fabs in Nanjing and in Chengdu. An OECD report lists some of these funds: the Beijing IC Industry Equity Investment Fund, with initial funding of about USD 5 billion (CNY 32 billion), involved in overseas acquisitions; the Shanghai Alliance Investment (SAIL), a venture-capital arm of the Shanghai Municipality has large stakes in Hua Hong (17%); and other local actors in the industry[106]. This is not only a public story – Huawei, for example, has established in April 2019 Hubble Technology Investment, which operates mainly in the acquisition of minority stakes in local semiconductor equipment companies, to decrease Huawei's dependence on foreign supplies[107]. And China has many venture capital actors, some that draw capital from the Silicon Valley, who support its start-up scene in IC design[108].

In addition to these funds, **the capital market is attractive for investors: the US offensive has generated a patriotic speculative gamble on the domestic semiconductor industry.** In July 2019, the Shanghai Stock Exchange Science and Technology Innovation Board (STAR market) was inaugurated on the Shanghai stock exchange, **with the ambition of becoming the Chinese equivalent of the Nasdaq.** It aims to facilitate China's technology giants' IPOs. One year after its inauguration, **STAR counts 123 listed companies, including 12 in the semiconductor sector.** The STAR market is also a response to the Sino-American decoupling in the high-tech sector. It offers an alternative to Chinese firms that encounter problems in New York, and for those who want a secondary listing (around a hundred Chinese companies are listed in the United States), it is an alternative to being listed in Hong Kong. SMIC is an excellent example. **After China's leading foundry decided to leave New York in 2019 because of the low number of transactions of its stock, it raised USD 6.6 billion on the day of its STAR listing, in July 2020[109].**

However, China faces issues of optimal allocation of public resources, as denounced by the National Development and Reform Commission in October 2020 in an unusually harsh statement. Meng Wei, an NDRC spokesperson, attacked many companies **for having "blindly taken on projects" in the industry to attract public funding,**

106 OECD, Measuring distortions in international markets: the semiconductor value chain, *OECD Trade Policy Paper no. 234*, December 2019, http://dx.doi.org/10.1787/8fe4491d-en
107 "Huawei invests in China chip groups as US curbs strangle supplies", *Financial Times*, December 7, 2020, https://www.ft.com/content/7913e2ad-78b9-4d32-874b-f63980a15d26
108 "Start-up Funding: May 2020", *Semiconductor Engineering*, June 8, 2020, https://semiengineering.com/startup-funding-may-2020/
109 "SMIC shares soar in Shanghai, in a successful debut that may give more Chinese stocks confidence to leave US market", *South China Morning Post*, July 16, 2020, https://www.scmp.com/business/companies/article/3093370/shares-chinas-largest-chip-maker-smic-more-triple-shanghai

despite a total lack of experience, know-how and even human capital, leading to a major waste of public resources[110].

The NDRC official was certainly referring to the spectacular failures of Wuhan Hongxin and Tsinghua Unigroup. Shortly after his statement, institutional investor Tsinghua Unigroup had to default on a USD 198 million private bond at the end of 2020. While there is no immediate risk of collapse given the support Tsinghua Unigroup receives from the public banking sector, the episode highlighted the risky investment and borrowing behavior of the company in support of China's semiconductor industry[111]. Later in December, it announced defaulting on USD 2.5 billion of offshore bonds[112]. According to Caixin, Tsinghua Unigroup's liabilities totaled USD 8 billion as of September 2020, with a majority short-term[113]. The default is related to bad acquisitions and may signal a change of China's policy approach with regards to financing the country's ambitions in the semiconductor industry. The signal will be unmissable if the central government lets Tsinghua Unigroup fail. Given that Tsinghua University is the alma mater of Chinese leader Xi Jinping, this will mean no favorable treatment, and an intention to let fail the companies that have taken excessive risks. Bailing out Tsinghua Unigroup would send the opposite signal.

What is clear is that China's quasi whatever-it-takes approach to public support for the semiconductor industry has led to severe waste and misallocation of resources. As a result, there is a disconnection between industrial development and market demands, and a lack of positive synergies that prevent China from fully benefiting from its market scale advantage[114]. **This is a persistent weakness of China's state capitalism.** At the same time, the system allows waste, and waste in some projects does not mean that all projects will fail. Winners emerge in spite of waste, as public funding does not entirely evaporate.

110 "Beijing to Inexperienced Companies: Stay Out of Chipmaking", *Caixin*, October 21, 2020, https://www.caixinglobal.com/2020-10-21/beijing-to-inexperienced-companies-stay-out-of-chipmaking-101617267.html
111 "Tsinghua Unigroup default tests China's chipmaking ambitions", *Nikkei Asia*, November 18, 2020, https://asia.nikkei.com/Business/China-tech/Tsinghua-Unigroup-default-tests-China-s-chipmaking-ambitions
112 "China's Tsinghua Unigroup bond crisis deepens with second default", *Nikkei Asia*, December 10, 2020, https://asia.nikkei.com/Business/Markets/China-debt-crunch/China-s-Tsinghua-Unigroup-bond-crisis-deepens-with-second-default
113 "Exclusive: Chipmaker Tsinghua Unigroup Set to Meet Bondholders as Interest Comes Due", *Caixin*, December 1, 2020, https://www.caixinglobal.com/2020-12-01/exclusive-chipmaker-tsinghua-unigroup-set-to-meet-bondholders-as-interest-comes-due-101634539.html
114 "广发证券:国家集成电路产业基金一期投资解析" (GF Securities: National Integrated Circuit Industry Fund Phase I Investment Analysis), Xinlang Caijing, March 13, 2019, https://finance.sina.com.cn/stock/hyyj/2019-03-13/doc-ihsxncvh2157328.shtml

3. Access to foreign technology: successes and the pushback

The conjunction of abundant capital and technology needs has **generated a strategy of acquiring foreign assets for technology transfer purposes.** This has been one of the purposes of the Big Tech Fund, but Tsinghua Unigroup and other funds have also been active in international markets to support acquisitions.

Table 6: Chinese and American acquisitions in the European semiconductor industry, 2015-2020

Target firm	Target firm's country of origin	Buyer	Buyer's Country of Origin	Date	Transaction cost (USD)
Ampleon (NXP former division)	Netherlands	JAC Capital	China	2015	1.8 billion
Silex Microsystems	Sweden	NavTech (Beijing Navgnss Integration Co., Ltd.)	China	2015	Undisclosed
GreenPeak Technologies	Netherlands	Qorvo	USA	2016	Undisclosed
Galaxy Semiconductor Inc	Ireland	Mentor Graphics Corporation	USA	2016	Undisclosed
LFoundry	Italy	SMIC	China	2016	49 million
Yogitech	Italy	Intel	USA	2016	Undisclosed
Okmetic	Finland	China's National Silicon Industry Group (NSIG)	China	2016	Undisclosed
Nexperia (NXP former division)	Netherlands	JAC Capital	China	2016	2.75 billion
14.5% of Soitec	France	China's National Silicon Industry Group (NSIG)	China	2016	Undisclosed
Norstel	Sweden	An Xin Capital	China	2017	Undisclosed
Imagination Technologies	UK	Canyon Bridge	China	2017	744 million
Nexperia (controlling stake)	Netherlands	Wingtech Technology	China	2019	3.6 billion
CommSolid	Germany	Shenzhen Goodix Technology	China	2018	Undisclosed
Linxens	France	Tsinghua Unigroup	China	2018	2.6 billion

.../...

Target firm	Target firm's country of origin	Buyer	Buyer's Country of Origin	Date	Transaction cost (USD)
NXP's voice and audio business	Netherlands	Shenzhen Goodix Technology	China	2019	Undisclosed
Anteryon	Netherlands	Jingfang Optoelectronics (WLOPT)	China	2019	36.7 million
DecaWave Limited	Ireland	Qorvo	USA	2020	400 million
ARM	UK /Germany	Nvidia	USA	Intended	40 billion
MueTec Automated Microscopy and Messtechnik GmbH	Germany	TZTEK Technology	China	Intended	20.5 million

The big picture of China's overseas acquisitions in the semiconductor industry combines three dimensions: **failed attempts to purchase giants in the IC manufacturing and design segment; some successes in Semiconductor equipment; and a trail of stories linked to dual-use items with possible military end-users.**

China's main setbacks have happened in the United States and in Taiwan. Between 2014 and 2018, CFIUS blocked five transactions in the semiconductor sector: the acquisition of Xxera in 2018, Lattice and Global Communication Semiconductors in 2017, and Aixtron and Philips Lumileds in 2016. During the same period, around 10 transactions were approved. Tsinghua Unigroup, the company facing bond defaults at the end of 2020, made a USD 23 billion offer to acquire memory chip giant Micron in 2015[115]. During a 2015 visit to Taiwan, Tsinghua Unigroup's Chairman also told Taiwanese media that he would be interested to acquire leading IC design house MediaTek if the Taiwanese government lifted the ban on Chinese tech investment[116]. He also offered to buy a stake in TSMC, to which TSMC founder Morris Chang reportedly answered: "I'm afraid you can't afford it"[117].

Smaller acquisitions downstream were more successful. And as table 6 shows, like the United States, **Europe has been on the receiving end of Chinese acquisitions in the past five years.** Most notably, with support from the Big Fund, investment fund China's National Silicon Industry Group (NSIG) made two major acquisitions in the Semiconductor equipment in 2016: Finnish wafer producer Okmetic, and 14.5% of the French company Soitec. Soitec has a monopoly for the production

115 "Exclusive: Micron does not believe deal with Tsinghua is possible – sources", *Reuters*, July 21, 2015, https://fr.reuters.com/article/idUSKCN0PU1X120150721
116 "China's Tsinghua interested in MediaTek", *EETimes*, November 3, 2015, https://www.eenewseurope.com/news/chinas-tsinghua-interested-mediatek
117 "Tycoon recalls Chinese chipmaker Tsinghua Unigroup's bid for Taiwan TSMC 5 years ago", *Taiwan News*, November 16, 2020, https://www.taiwannews.com.tw/en/news/4054956

of Silicon-on-Insulator, a standard component of radio frequency chips that allows reduction of power consumption. SMIC acquired 70% of Italian company LFoundry in 2016 as well, with an aim to step into the automotive electronics market[118].

In Europe, the most revealing case of acquisitions motivated by technology access for military purposes and backed by the Chinese state is Navtech's purchase of Swedish company Silex, with the support of the CICIIF via a subsidiary. Navtech – the former name of Sai Technologies – is a private Chinese company specializing in navigation technologies with applications in aviation, space programs, and the arms industry. Silex specializes in micro-electromechanical systems, which find applications in particular in industrial semiconductor manufacturing processes in the field of microscopic sensors. This acquisition led to the construction in Beijing of a new factory using Silex technology[119].

Another case of dual-use acquisition with a significant impact on a military end-user in China is the 2008 purchase of British semiconductor company Dynex Power Inc. by a subsidiary of China's state-owned railway giant, CRRC Corporation Limited, the largest rolling stock manufacturer in the world. Dynex has a specialization in high power semiconductors. Dynex technology has been reportedly used in the PLA's electromagnetic systems, which include the development of a railgun for the Navy, and possibly as ground systems, and in the development of catapult technology for the next generation of China's aircraft-carriers[120].

The Silex and Dynex cases are typical of the dual-use technology transfers that European regulators would be much more likely to block in 2021. But the semiconductor industry is under greater scrutiny not only because of dual-use possibilities, but as a result of the increased vigilance in Europe towards Chinese investment in technology-intensive sectors and critical infrastructure. Whether a transaction such as the 2018 acquisition of Luxens, a dynamic French semiconductor company specializing in magnetic card connectors, for USD 2.6 billion by Tsinghua Unigroup would be unconditionally approved in 2021 is questionable. **The technology acquired is not particularly sensitive as the world moves to e-payments, but the scale of the transaction and the changed atmosphere regarding Chinese acquisitions in Europe suggests that the same deal today would get more scrutiny than it did in 2018.**

118 "SMIC Acquires LFoundry and Enters into Global Automotive Electronics Market", SMIC website, June 24, 2016, https://www.smics.com/en/site/news_read/4559
119 "How China acquired mastery of vital microchip technology", *Financial Times*, January 29, 2019, https://www.ft.com/content/7cfb2f82-1ecc-11e9-b126-46fc3ad87c65
120 Anja Manuel, Kathleen Hicks, "Can China's Military Win the Tech War?", *Foreign Affairs*, July 29, 2020, https://www.foreignaffairs.com/articles/united-states/2020-07-29/can-chinas-military-win-tech-war

Overall, access to foreign technologies through acquisitions is drying up but not stopping. In Europe, in 2020, TZTEK, a Suzhou-based testing firm, acquired MueTec, a German equipment supplier. **Signs point to acquisitions becoming more difficult but continuing, as Western states seek to protect their companies amidst a technological competition with China and are more caution to the possible uses of these technology transfers by the army and public security.** Through the PACTE Law of May 2019, France now enforces a prior authorization system for foreign investment in the semiconductor industry – expanding to high-tech a system initially built for the arms industry. In the Netherlands, the question of licensing ASML's EUV machines for exports to China has given rise to a larger conversation regarding technology transfers.

Finally, **intangible technology transfers take place through R&D cooperation, an area that is subject to very little control besides the internal policy and practices of the research institutes.** For example, SMIC's 14 nm fin field-effect transistor (finFET) process has relied on a joint R&D technology venture created with Huawei, Qualcomm and the leading Belgian research center IMEC, which played an important role in the development of EUV technology[121].

4. The human resources challenge

In addition to access to foreign technology as a substitute to domestic innovation, Chinese companies need to find the key to an immensely difficult problem: human resources. A 2018 White Paper from the Ministry of Industry and Information Technology estimated **the talent shortage of the Chinese industry between 200,000 and 300,000 people if it is to catch up and achieve strategic autonomy.** In recent years, recruitment from Taiwan, South Korea, Japan, the US and Europe has often hit the news.

In total, the *Business Daily* estimates that Taiwan has in recent years lost more than 3,000 engineers to its Chinese competitors in the industry[122]. The best known is none other than the first CEO of SMIC, Richard Chang, who crossed the Taiwan Strait in 2000 after his company was acquired by TSMC. In 2020, Quanxin Integrated Circuit Manufacturing (Jinan) and Wuhan Hongxin Semiconductor Manufacturing recruited around

121 Mark LaPedus, "China Speeds Up Advanced Chip Development", *SemiEngineering*, June 22, 2020, https://semiengineering.com/china-speeds-up-advanced-chip-development/
122 "中國企業開出2至3倍薪資挖角 台灣已流失3000多名半導體業人才", (China digs talent with salaries two to three times higher, Taiwan's semiconductor industry has already lost 3000 qualified professionals), *CNMedia*, December 3, 2019, https://www.cmmedia.com.tw/home/articles/18815

100 engineers from TSMC, offering salaries more than 2.5 times higher than the average market rate, bonuses, and various compensations ranging from housing to regular round trips to Taiwan[123]. The beginning of this brain drain can be dated in 1989 with a Taiwanese investment in Zhuhai, shortly after the Taiwanese government removed the prohibition of cross-strait contacts; in 2007, the Taiwanese workforce at SMIC comprised 650 engineers[124]. In addition to engineers, China has also focused on top executives, such as Liang Mong-Song (co-CEO of SMIC, former chief of TSMC's R&D department), Charles Kao (nicknamed "Taiwan's DRAM godfather", who served five years as executive vice president of global operations at Tsinghua Unigroup) or Sun Shi-wei (former vice chairman at United Microelectronics Corp, who was also recruited by Tsinghua Unigroup).

This brain drain is very difficult to curb, but industry stakeholders nevertheless believe that China's efforts are insufficient to solve its HR problem. Former CEO of UMC Jackson Hu believes that "the degree of specialization required for process technology is so high that Chinese companies would need entire teams"; individual recruitments or recruitment of small teams will not suffice[125]. **In addition, this is a risky move for Taiwanese engineers as a return to Taiwan is not an easy option,** because of a corporate culture that values loyalty, while by contrast the long-term integration of Taiwanese engineers and executives in Chinese companies is not a given. The Taiwanese industry thus tends to see crossing the Strait as a one-shot no-return career-end move.

EDA software, one of the two main chokepoints constraining China's progress, epitomizes the human resources problem faced by the industry. In 2020, there were about 1,500 EDA software development engineers of Chinese nationality, but less than 300 worked in Chinese EDA companies. **The large majority worked for the three industry leaders: Cadence, Synopsis and Siemens EDA.** By comparison, Synopsis had 5,000 engineers working directly in EDA software development and 2,000 working in IP[126]. To make up for this shortage of EDA software talent, Chinese EDA start-ups have started recruiting engineers and executives from the US leading firms. A Nikkei Asia investigation from November 2020 shows this recruitment effort, including by one start-up in which Cadence holds shares, a reminder if needed that the global leaders are closely monitoring Chinese efforts[127].

123 "China hires over 100 TSMC engineers in push for chip leadership", *Nikkei Asia*, August 12, 2020, https://asia.nikkei.com/Business/China-tech/China-hires-over-100-TSMC-engineers-in-push-for-chip-leadership
124 Monique Chu, *The East Asian Computer Chip War*, Routledge, 2013.
125 Quoted in Mathieu Duchâtel, "Huawei's 5G Supply Chain: Taiwan Winning Twice?", Institut Montaigne, October 29, 2019, https://www.institutmontaigne.org/en/blog/huaweis-5g-supply-chain-taiwan-winning-twice
126 Litho World, "Current Status of the Integrated Circuit Industry in China – EDA Industry Review", *Journal of Microelectronic Manufacturing*, vol. 2, issue 3, September 2019, http://www.jommpublish.org/p/36/
127 "China aims to shake US grip on chip design tools", *Nikkei Asia*, November 25, 2020, https://asia.nikkei.com/Business/China-tech/China-aims-to-shake-US-grip-on-chip-design-tools

V

CONCLUSION

China's efforts are impressive. They are however likely to be insufficient to reach the goals set by the Communist Party for the semiconductor industry. Three main weaknesses will likely persist: foreign obstacles to access to technology; lack of human resources; and a system that does not allow an optimal allocation of resources and fails to take full advantage of China's market scale. Of these, **controls over tech transfers are the obstacle on which Chinese policies will have the least effect.** They depend on China's leverage to some extent. But the decisive factor will remain **the policies of the United States, Japan, Korea, Taiwan and the leading European countries in the semiconductor industry, especially France, Germany, the Netherlands and the UK.**

These weaknesses will make it difficult for China to truly dominate the digital revolution enabled by 5G infrastructure, through the growth of the industrial applications of cloud services, big data and artificial intelligence, and progress in computing power, including for mobile devices and connected objects. **China will of course not miss the digital revolution – it will remain a leader in many segments,** given that not all applications need self-reliance in the semiconductor industry, or being a leader in IC design and manufacturing. Its industrial capacity will remain a huge asset to increase the scale of production when needed, for applications such as the automotive industry and new semiconductor materials. In high-growth segments such as AI chip design and edge computing, China is not far behind the global leaders and may do more than catch-up. And for many applications, China's IC capacities will be sufficient. **But the race is also about future innovation linked to the newest generations of chips, at 7, 5, 3 and 2 nanometers.** There, China faces a bottleneck and leadership status will be hard to reach. In addition, while the arms industry does not currently require access to the most advanced IC manufacturing processes, the digitalization of weapons systems means that military R&D will benefit from access to those newest generations of chips – this is one factor explaining the investment of the US federal government to subsidize the construction of an advanced TSMC fab in Arizona.

The future of China's IC industry depends on decisions that will be taken in the United States, and on other technology transfers barriers that will be erected elsewhere. America's domination in IP, design software and semiconductor manufacturing equipment will not disappear easily. **As the Biden administration refines its policy plans**

and gets its key officials approved by Congress, China places hopes on a more relaxed approach. But a scenario of further extension of technology transfer restrictions cannot be ruled out. How will the Biden administration use the US's leverage and the extraterritorial provisions of US legislation will be a decisive factor shaping the future of China's semiconductor industry, confirming the accuracy of Xi Jinping's 2016 remark that "our dependence on core technology is the biggest hidden trouble for us".

VI

IMPLICATIONS FOR EUROPE AND POLICY RECOMMENDATIONS

The US-China technology "war" is a wake-up call regarding **the need to act strategically about Europe's position in the semiconductor supply chain.** It brings to light three potential risks for Europe.

- **What if the European semiconductor industry lost market access to Chinese customers?**
- **What if the technology transfer restrictions implemented by European regulators and companies were taken advantage of by competitors in the United States and elsewhere?**
- **What if the European industry lost access to the most advanced foundries, currently located in South Korea and in Taiwan, and tomorrow in Arizona as well?**

In the latter case, the risk is not so much geopolitical as one of insufficient global capacity – and the recent examples of masks and vaccines show that this is not a theoretical issue. These risks force Europe to have to think strategically about the semiconductor supply chain, and to work on its own strengths to ensure its interests are not jeopardized by geopolitics beyond its control.

Year 2021 will be pivotal to the future of microelectronics in Europe in this international context where geopolitics, industrial policies and technology transfer controls redefine the rules of dependence and interdependence in the semiconductor industry. There is strategic awareness at the European Commission and in several EU Member States. On December 7, 2020, 18 EU Telecommunication Ministers signed a **joint declaration to bolster Europe's semiconductor and processor technology**[128]**.** The declaration is a commitment by Member States, supported by the Commission, to work together to develop in Europe the capacity to "design and eventually fabricate

128 European Commission, Press Release, "Member States join forces for a European initiative on processors and semiconductor technologies", *Shaping Europe's Digital Future*, December 7, 2020, https://ec.europa.eu/digital-single-market/en/news/member-states-join-forces-european-initiative-processors-and-semiconductor-technologies

the next generation of trusted, low-power processors, for applications in high-speed connectivity, automated vehicles, aerospace and defense, health and agri food, artificial intelligence, data-centers, integrated photonics, supercomputing and quantum computing". In practice, the joint declaration calls for **making full use of the 20% of the European Recovery and Resilience plans that is planned to foster Europe's digital transition, to support the European microelectronics industry, and in particular research, design and manufacture for processors – 20% would represent up to EUR 145 billion over the next 2 to 3 years.** Moreover, the declaration recommends the drafting of a proposal for a second Important Project of Common European Interest, an EU Instrument that channels funding to a specific industrial project – the only existing ones so far are for electric batteries and hydrogen production.

As the strategic awareness regarding Europe's potential future vulnerabilities progress in European policy circles, the main questions are about policy choices, planning for efficiency and the optimal use of available resources.

Recommendation no.1: Focus policy support on Europe's chokepoint technology (EUV lithography, EDA software tools) and key strengths (IC design for the automotive industry, microcontrollers, low-power technologies).

For the European semiconductor industry, **China's ambitions in the sector are a growth opportunity and a competitive challenge in all the segments of the industry.** From the perspective of long-term resilience to geopolitical risk, Europe has an interest to maintain a complete industrial value chain in Europe, from equipment and IC design to manufacturing and testing. **But an optimal use of resources should focus on leveraging Europe's strengths to nurture the dependence of other players on European products.** This is a realistic and more cost-effective approach – self-reliance is not an option, and Europe needs leverage to ensure it thrives in an interdependent supply chain characterized by targeted technology transfer restrictions.

Europe has industrial gems in lithography, EDA software and IC chip design for specific industries where Europe has leaders, such as the automotive industry, but also aeronautics, defense and telecoms.

EUV lithography will remain a European strength for years to come despite the Chinese attempts to catch-up. There is possible competition from Japan (Canon and Nikon), but it is extremely unlikely that a Japanese government would authorize the sale of EUV machines to China, if Japan engaged in the production of EUV technology, given the structural rivalry between China and Japan in Asia. The European Commission and Member States can support EUV lithography by supporting its chain of suppliers – ASML sources products from many suppliers across Europe, and as it scales up production of EUV machines, some of these smaller companies could need public support to accompany the growth of ASML's manufacturing capacity.

EDA software is mainly an American strength, **but it is also a chokepoint technology with a major European player, Siemens EDA.** The development of European intellectual property for software specifically designed for the needs of the microelectronic industry should be seen as a matter of strategic resilience.

Developing Europe's strengths also **means a focus on some specific industrial end-users, especially the automotive industry, but also aeronautics and defense, and possibly telecommunications.** Interestingly, with the automotive industry for which NXP, Infineon and STMicroelectronics are big players, the Chinese market will remain attractive and beyond the reach of technology transfer restrictions. A recent MERICS study has shown that 26.9% of Infineon sales were going to the Chinese market in 2019, an increase from 24.3% in 2016. NXP's decreased from 40.6% in 2016, but were at a high level in 2019, at 36.5%[129]. Infineon CEO Reinhard Ploss has pointed out that the company's sales to China were more related to China's industrial development than to 5G networks[130]. The Chinese automotive industry, with clients such as Geely and BYD, and China's ambitions for e-mobility are a key business for European IC manufacturers, and an engine of future growth. In that area of strong market position for European firms, the game will be to consolidate leadership and the Chinese market will be instrumental in reaching that goal.

129 Max Zenglein, "Mapping and recalibrating Europe's economic interdependence with China", *China Monitor*, MERICS, November 17, 2020, https://merics.org/en/report/mapping-and-recalibrating-europes-economic-interdependence-china

130 "Infineon insulated from U.S.-China tensions: CEO", *Reuters*, November 18, 2020, https://www.reuters.com/article/us-tmt-conference-infineon/infineon-insulated-from-u-s-china-tensions-ceo-idUSKBN27Y2RN

Recommendation no.2: Prioritize research and development.

The foundations of European strengths listed above are Europe's R&D capacities, in private companies and in research centers such as Fraunhofer in Germany, IMEC in Belgium and LETI in France. IMEC has played a key role in the development of EUV technology. LETI is a strong source of support for the Grenoble semiconductor ecosystem in France. Fraunhofer has key strengths in automotive applications. **Europe's focus on its key industrial strengths should prioritize the R&D foundations of these strengths to ensure their sustainability.**

The United States is moving fast on the front of federal support for semiconductor R&D. The 2021 National Defense Authorization Act authorizes federal incentives to promote semiconductor manufacturing and federal investment in research as part of legislation aiming at "creating helpful incentives to produce semiconductors for America". Specific funding packages will need to be approved by the US Congress.

As the Moore Law is close to reaching its physical limit with the development of 2 nm process technology in Taiwan and South Korea, the future of the semiconductor industry may depend on alternatives to silicon. Research on the most promising alternatives, Gallium Nitride and Silicon Carbide, is an important area – especially research on their industrialization, which ultimately could give China an advantage given the scale of its industrial structure.

Recommendation no.3: Hold in 2021 a European conference with all stakeholders from industry and government, to examine options and the costs of building an advanced foundry in the European Union.

In his speech at Hannover Messe Digital Days, Commissioner Breton set the highly ambitious objective of producing the most advanced processors (2 to 3 nm) in Europe and reach 20% of the world's capacity in value for IC manufacturing[131]. **This would be achieved by launching a European alliance on microelectronics,** which would

131 European Commission, "Speech by Commissioner Thierry Breton at Hannover Messe Digital Days", July 15, 2020, https://ec.europa.eu/commission/presscorner/detail/en/SPEECH_20_1362

combine an initial combined private investment of EUR 20/30 billion and support both R&D and production pillar.

Building an advanced foundry in Europe would fit the narrative of European strategic autonomy. In reality, the main market of such a foundry would not be European, as pure digital manufacturers needing semiconductors below the 7 nm generation are mostly located in the United States and in East Asia. In addition, most industrial players argue that Europe would have a greater chance to have an advanced foundry on its soil by working with TSMC and Samsung than by aiming to upgrade of the existing foundry capacities of its IC manufacturers. This is because they already master the technology, including EUV lithography, and the complex industrial process. **Attracting TSMC or Samsung to invest in Europe becomes an issue of the right incentives, but also of competition with the US,** and possibly with Japan, as Japan is also contemplating attracting a TSMC fab on Japanese soil. This raises issues of human resources and environmental standards, as a fab has huge needs in terms of water and electricity, and creates pollution.

Having an advanced fab in Europe would bring some very important potential benefits. **It would create a virtuous circle for Europe's IC industry as a whole, and for the fundamental S&T level of the continent in microelectronics. It would have a positive effect on highly skilled employment and on an ecosystem of suppliers,** including among start-ups. It would support private R&D. In addition, the US approach is a reminder that the next generation of integrated circuits will be progressively integrated into the arms industry. Europe has a stake in having European suppliers for its military forces.

The ongoing TSMC investment in Arizona shows that a 5 nm fab requires at least an initial USD 12 billion of capital expenditure. **This is a huge investment, but Europe has the resources in public and private capital – this is a matter of strategic prioritizing,** in the context of the adoption of the European Recovery and Resilience plan, and the debate launched on addressing semiconductors as an Important Project of Common European Interest. It is hard to imagine a better timing to conduct in-depth consultations with all stakeholders and agree on a strategic course.

Recommendation no.4: Strengthen technology transfer controls to address the issue of military end-users in China.

The military end-use of semiconductor technology is a serious issue from the perspective of peace in East Asia. Today's weapons systems do not rely on the most advanced foundries, but digitalization of the arms industry is an ongoing process. In many cases, **it will be an extremely complex process to distinguish between civilian and military end-users of a specific technology, and diversion is always possible.**

The ASML EUV machine epitomizes this problem. EUV lithography is about pure digital applications, hence not directly military. But they are a focus of export control discussions from a military end-use angle precisely because access to that technology would enhance the S&T level of China to the extent that the fundamentals of its arms industry would be upgraded.

In recent years and in particular under Xi Jinping, the perception in Beijing that there is a reduction in the power gap with the US has worked as an incentive for China to behave more aggressively on the international front – in the Taiwan Strait, in East Asian maritime disputes, at the border with India, in using economic coercion and bullying against Australia or South Korea. Given the importance of semiconductors for military applications, **there should be a shared recognition among allied countries that maintaining a technology gap with China is in the interest of international security.**

For Europe, this requires **strict implementation of the investment screening regulation to prevent intangible technology transfers.** This requires a **close look at education and research cooperation in microelectronics that enhances the capacity of military end-users in China,** as licensing does not cover transfers of data and knowledge. This also requires **building an intra-European consensus on what semiconductor technology needs to be export controlled, and whether Wassenaar is sufficient.** The semiconductor industry is so foundational as an enabler of all high-tech and digital industries and so important from the perspective of great power competition that specific export control measures may be needed as a policy instrument, not to curb trade but to nurture European strengths.

European policymakers should not be misled by the narrative that controls over technology transfers will undermine the growth prospects of the European semiconductor industry in China. The importance of the automotive sector in Europe-China trade is a guarantee of stability.

Recommendation no.5:
Build transatlantic convergence on technology transfers in the semiconductor industry as a matter of strategic priority in 2021.

The next six months will be crucial for transatlantic relations on China policy. The European IC industry distrusts the intentions behind the action of the US with regards to technology transfer restrictions. **Many actors think that US restrictions are commercially motivated, rather than serving the US interest in great power competition with China, especially its military dimension.** The transatlantic alliance needs a **sense of common political purpose** to address technology transfers to China to be established during the first months of the Biden administration. Otherwise, the issue will continuously undermine the alliance.

The immediate issue is Huawei, and the Biden administration's approach to licenses under the current US export control regime will be a test case for transatlantic relations. Clarity is needed on the criteria that will determine the granting or denial of a license. A sense that licenses are being used to favor US companies over their competitors in Europe would undermine the basis for transatlantic cooperation in technology transfers. **Cooperation will not dispel the elements of competition between the European and American tech industries, but it should address the suspicion in the European industry that US export controls targeting China also aim at strengthening US firms vis-à-vis their European competitors.** This suspicion is based on a historical record of industry stories of American companies replacing European competitors after license denials. In that regard, having a specific point of contact for China-related issues at the US Bureau of Industry and Security would be a welcome move for European companies.

But transatlantic cooperation on semiconductor technology is about more than licensing issues and US extraterritorial practices. **The transatlantic alliance is a strong foundation to address technology transfers to third countries, and a positive agenda is possible.** For one thing, there is a realistic incentive for Europe to work within the framework of the transatlantic alliance: the US owns more chokepoints than Europe, in terms of design capacities and EDA tools, and the pure digital market is so far dominated by American and East Asian firms. Building increased convergence on the **three pillars of technology transfer controls (export control, investment screening and regulation of education and research cooperation)** should be complemented by industrial partnerships where possible in the semiconductor industry.

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The opinions expressed in this policy paper are not necessarily those of the above-mentioned persons or of the institutions that they represent.

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THERE IS NO DESIRE MORE NATURAL THAN THE DESIRE FOR KNOWLEDGE

The Weak Links in China's Drive for Semiconductors

"Our dependence on core technology is the biggest hidden trouble for us", said Xi Jinping in 2016. Semiconductors are crucial to China's global leadership ambitions - but China's trouble is no longer hidden, despite massive policy support to a booming sector. For a long time, interdependence was a major asset for China, irrigating the rapid growth of its microelectronic industry. But this period may be coming to an end, due to an American offensive that takes advantage of China's dependence on foreign technology.

This policy paper describes the state of China's semiconductor industry, provides an analysis of the strengthening of technology transfers controls in the United States, reviews China's current industrial policies to overcome its weaknesses and draws implications and recommendations for the European semiconductor industry. It highlights the chokepoint technologies that slow down China's ambitions for an "innovation-driven development strategy".

The paper concludes that Europe should act fast and play on its strengths in a strategic sector at the heart of the US-China tech rivalry. Interdependence is no longer a given, and the US-China technology rivalry will not disappear overnight. As the strategic awareness regarding Europe's potential future vulnerabilities progresses in European policy circles, the main questions are about policy choices, planning for efficiency and the optimal use of available resources. The author provides five recommendations to reduce Europe's exposure to future geopolitical shockwaves.

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