The East Asian semiconductor industry – history, geoeconomics and supply chain realignments

Tobias Junerfält [1]

East Asia has become a major geopolitical arena during the first decades of the 21st century, following US-China great power competition. Moreover, the prospect of a Chinese invasion of Taiwan, geoeconomic competition and events such as the covid-19 pandemic and Russia's full-scale invasion of Ukraine in 2022, have shed light on vulnerabilities in global supply chains for critical goods. Supply chain vulnerabilities become especially salient for goods whose suppliers are scarce and concentrated in specific countries or regions. Semiconductors is one such category of goods, and much of the semiconductor industry is located in East Asia. This memo explores the historical background of the East Asian semiconductor industry, its current structure, supply chain risks and future developments, with a focus on geoeconomics.

Semiconductors constitute crucial components for electronic goods produced and used in a wide variety of economic sectors. Civilian industries rely on a steady supply of various semiconductors in order to produce computers, smartphones, domestic appliances, cars and spacecraft, among many other things. Likewise, defence industries cannot produce modern tanks, radar systems, submarines or intercontinental ballistic missiles, just to name a few examples, without semiconductors. The national security implications of semiconductor supply are wider than merely weapon systems for the military, since for example critical infrastructure such as data centres also require semiconductors to function. Not all technological goods necessarily require the most advanced semiconductors in order to perform their task; for instance, most military equipment as well as automotives are heavily dependent on so-called legacy semiconductors. However, without access to advanced semiconductors the development of cutting-edge technologies is significantly slowed down or even rendered impossible.[2] Tech rivalry and control over the semiconductor supply chain are important aspects of US-China great power competition, as the computing power provided by advanced semiconductors, and what it means for both offensive and defensive military capabilities, can be decisive for the future US-China military balance.

Taiwan Semiconductor Manufacturing Company (TSMC), has been recognised as being an actor of central importance for the production of advanced semiconductors. However, even though Taiwan's semiconductor industry, with TSMC as its frontrunner, is of great significance, the global semiconductor industry is characterised by a large degree of international supply chain dependencies for different parts of the production process and for the necessary inputs. Other countries in East Asia, namely Japan, South Korea and China, also play important roles in the semiconductor industry. Outside of East Asia, the US and the Netherlands are other important semiconductor industrial nations. At the same time, the US has close bilateral ties and military alliances with both South Korea and Japan, as well as close non-diplomatic relations with Taiwan. There is thus a geopolitical aspect of the global semiconductor industry, with a US-oriented camp on one side, and China on the other.

The purpose of this memo is to study current and future supply chain risks and developments for the semiconductor industry, with a special focus on East Asia and geoeconomics, herein defined as *state-initiated use of economic*

1 The author is indebted to Jared Mondschein at RAND Corporation for reviewing the memo and sharing his expertise. The author is also grateful to the following FOI colleagues: Ian Anthony for language-editing, Lena Engelmark for layout-fixes, Maria Ädel for editorial comments, and Niklas Rossbach for helpful advice in the initial stages of writing this memo.

2 A representative of the Taiwanese semiconductor industry, interview by author, Taipei, Taiwan, 4 July, 2023. "Legacy" is a relative term that refers to older-generation semiconductor technology.

FOI Memo: 8468
Project no: A12318
Approved by: Ulf Jonsson

March 2024

means in international rivalry to further foreign policy goals or promote national interests. The source material includes literary sources, but also in person interviews with representatives of the Taiwanese semiconductor industry, and online interviews with East Asian experts in foreign relations and geoeconomics.[3] The memo begins with a brief account of the historical development of the East Asian semiconductor industry, also including the US due to its role as the cradle of the semiconductor industry. Thereafter, an overview of the supply chain positions of the Taiwanese, Chinese, Japanese and South Korean semiconductor industries is provided. This is followed by an account of semiconductor supply chain risks, focusing on the on-going geoeconomic rivalry centred on US-China great power competition. Moreover, recent industrial policy initiatives around the world and the associated challenges ahead are described, drawing on historical experiences in East Asia. The memo concludes by discussing future developments and by listing some questions of relevance for Sweden and its defence sector.

A short history of the semiconductor industry[4]

The modern history of the semiconductor industry can be traced to the end of the 1940s and the invention of the germanium transistor, an electronic component made by semiconductor material, i.e. a semiconductor component. The invention was made at the US research company Bell Labs, which at the time belonged to the likewise US telecom giant AT&T. Some years later, during the latter half of the 1950s, an electrical engineer at the US tech company Texas Instruments successfully attempted to combine multiple transistors using a silicon wafer, which signified the birth of the first integrated circuit, what is today commonly referred to as a "chip".[5] Initially, the US military as well as space industry constituted the main customers for the nascent US semiconductor industry. For example, Texas Instruments kick-started their business through contracts with the US navy and air force, whereas Fairchild Semiconductor – another leading company, regarded as the founder of Silicon Valley – designed chips for the computer that took Apollo 11 to the moon.[6]

Gradually, the semiconductor industry transitioned to producing components for commercial electronics, even though the defence industry remained an important customer. In 1968, former Fairchild Semiconductor employees founded another company that would turn out to be of decisive importance for the US semiconductor industry, namely Integrated Electronics, also known as Intel. During the years that followed, Intel pioneered the development as well as commercialisation of both memory chips and microprocessors, the latter of which paved the way for the personal computer revolution.[7]

Starting from the 1980s, the US semiconductor industry increasingly came to be challenged by foreign competitors. The Japanese semiconductor industry had been developing since the 1960s, when the US state actively supported Japan's consumer electronics industry through technology transfers and trade promotion. Electronic calculators was a major end product that drove semiconductor-demand in Japan at this juncture. Japanese companies also received domestic subsidies, as well as other types of support from the Japanese state, such as import quotas for US chips. Eventually, Japanese memory chips produced by companies such as Toshiba and NEC became comparable to those produced in Silicon Valley, in terms of quality as well as price. The US industry was now under pressure, even though Micron, a US semiconductor company founded in the late 1970s, managed to maintain the US' international competitiveness in memory chip production.[8]

In the 1980s, the South Korean semiconductor industry, with Samsung as vanguard, broke into the memory chip market. As with the case of the Japanese semiconductor industry, support from the US was crucial for the development of South Korea's semiconductor industry. Somewhat ironically, Silicon Valley perceived the Japanese semiconductor companies, which the US state had helped to foster, as the main threat. South Korean memory chip producers established themselves on the semiconductor market with the help of joint ventures and technology transfers initiated by US semiconductor companies, new sales opportunities made possible by the US-Japan trade wars, but also

3 By request, the Taiwanese interviewees are anonymised.

4 The history of the semiconductor industry provided in this section is largely based on Chris Miller's stellar monography on the subject. For the purposes of this memo, the account is intentionally abbreviated and simplified. Among other things, it is simplified in the sense that there were additional companies than those mentioned which were of significance for the rise and development of the semiconductor industry. There was also a high degree of internationalisation, not least in terms of American semiconductor factories situated abroad. For more details, see Chris Miller, *Chip War: The Fight for the World's Most Critical Technology* (New York: Scribner, 2022).

5 Miller, *Chip War*, 10–5.

6 吉田秀明，"半導体六〇年と日本の半導体産業，" 経済史研究 [Yoshida Hideaki, "Sixty Years of Semiconductors and Japan's Semiconductor Industry," *Research in Economic History*] 11 (March 2008): 44, https://www.osaka-ue.ac.jp/file/general/4284; Miller, *Chip War,* 14–5, 20–2.

7 Miller, *Chip War*, 67–70, 100, 126.

8 Miller, *Chip War*, 48–9, 82–4, 117-22; Yoshida, "Sixty Years of Semiconductors and Japan's Semiconductor Industry," 45–8.

through financial support from South Korea's government and banks. Meanwhile, a revolution was taking place within chip design in the US, the so-called Mead-Conway-revolution. Advanced chip design became simpler, which among other things laid the foundations for an international division of labour for chip design and –manufacturing.[9]

Japan was eventually outpaced by both the US and South Korea in the 1990s. Japanese semiconductor companies that had put all their eggs in the memory chip basket were unable to maintain their inventiveness, and eventually lost out against their foreign competitors. Japan's industry, together with the state, had put too much focus on capital investments and production capacity, too little on profitability. The decline of the Japanese semiconductor industry was part and parcel of Japan's overall economy stagnation during the 1990s. Towards the end of the decade, South Korea was the leading producer of memory chips, while the US and Intel dominated the microprocessor segment and thrived as PCs spread across the world.[10]

The 1990s was also the period during which the Taiwanese company TSMC established itself as a force to be reckoned with in the global semiconductor industry. The founder of TSMC, Morris Chang, had an educational background from US elite universities as well as a long career at Texas Instruments behind him. During his time at TI, Chang had realised that the development towards producing more and more complex chips would bring with it an increasing need for economies of scale, due to escalating costs for both production equipment and R&D. The business idea for TSMC was therefore to produce externally designed chips on a massive scale, which would turn out to be a winning concept. Through substantial financial state support and tax benefits, and in symbiosis with Silicon Valley "fabless" chip designers, TSMC became the first company to successfully realise the so-called foundry model within the semiconductor industry.[11]

China's semiconductor industry first started to become a competitive threat in the 2000s, despite a long history in China of attempts to establish a self-sufficient and internationally competitive semiconductor industry. Previous, unsuccessful attempts go back at least to the 1960s and 1970s and Mao Zedong's rule. While the US and Japan competed over the leading position in the semiconductor market, Chinese scientists and engineers were sent to the countryside for re-education during Mao's Cultural Revolution. However, during the first decade of the 21st century, China looked like it had the potential to achieve its semiconductor ambitions. A significant development was the founding of the Semiconductor Manufacturing International Corporation (SMIC) in Shanghai in the year 2000. The founder, Richard Chang, was a Chinese native who had grown up in Taiwan and who had spent a couple of decades working at Texas Instruments in the US. In other words, his background was not entirely unlike that of his namesake Morris Chang, founder of TSMC. Supported by the Chinese state, as well as by foreign investors including from the US and Japan, the goal of SMIC was clear: to become a new TSMC. The focus of SMIC was therefore not least on importing skilled labour from Taiwan. The ambitions of outcompeting TSMC as a leading foundry have thus far fallen short of the mark, but SMIC did have some notable successes during the early 2000s. Among other things, SMIC came close to overcoming the technological advantage of its competitors at one point, and managed to sign contracts as a chip manufacturer for large semiconductor actors, such as Texas Instruments in the US.[12]

The semiconductor industry continued to evolve during the first decades of the 21st century, in East Asia and beyond. Notable developments during the 2010s include Intel being overtaken as the world's most advanced chip manufacturer by TSMC and Samsung. Moreover, the East Asian semiconductor industry has felt the geopolitical impact of the rise of China and US-China great power competition. China's political leadership has further emphasised the development of its domestic semiconductor industry since the mid-2010s, which has brought about an increased threat perception in the US and among its allies in East Asia. Even though business competition remains an important

9 Yoshida, "Sixty Years of Semiconductors and Japan's Semiconductor Industry," 48–9; Miller, *Chip War*, 130–3, 136–40, 166.

10 Yoshida, "Sixty Years of Semiconductors and Japan's Semiconductor Industry," 51–2; Miller, *Chip War*, 68, 156–7. The memory chips referred to here are so-called Dynamic Random Access Memory (DRAM) memory chips, one of the primary types of memory chips.

11 Miller, *Chip War*, xxvi, 163–4, 166–8; Yu-Shan Su and Chih-Yuan Wang, "From founding company to global company: The case of Taiwan semiconductor manufacturing company," in *Proceedings of PICMET '14 Conference: Portland International Center for Management of Engineering and Technology; Infrastructure and Service Integration, Kanazawa, Japan*, *2014*, 3651–2, https://ieeexplore.ieee.org/document/6921333. "Fabless" (from *fabrication* and *–less*) is a concept that refers to semiconductor companies engaged in design but not manufacturing of semiconductor components. "Foundry" refers to semiconductor companies focused on mass manufacturing of semiconductor components.

12 John VerWey, *Chinese Semiconductor Industrial Policy: Past and Present* (Washington, DC: U.S. International Trade Commission, July 2019), 11–2, https://www.usitc.gov/publications/332/journals/chinese_semiconductor_industrial_policy_past_and_present_jice_july_2019.pdf; Miller, *Chip War*, 173–5, 178–81, 250–1.

factor, there is now an increased focus on the security-related implications of China's semiconductor ambitions.[13]

The 21st century development of, for example, artificial intelligence (AI), Internet of Things (IoT) and 5G, has generated demand for advanced semiconductors that are both sufficiently powerful and energy efficient. Part of the solution has been an increased focus on customised chips tailored for specific purposes. Moreover, the manufacturing of more advanced semiconductors would not have been possible without access to new manufacturing equipment, materials and transistor designs.[14] The vast capital expenditures associated with technological advancement and continued growth also serve to explain the high degree of market consolidation in the semiconductor industry, with very few companies present at the top.

Semiconductor manufacturing and the East Asian industry

The historical background of the semiconductor industry suggests that much of the industry has over time shifted away from the US to different countries in East Asia. In the 21st century, the production of semiconductors remains divided among different countries and companies, with East Asia as a key region. This section gives an overview of the semiconductor manufacturing process and the semiconductor industries in Taiwan, China, Japan and South Korea.

The semiconductor manufacturing process is divided into three overarching steps: chip design, front-end manufacturing and back-end manufacturing.[15] Front-end manufacturing involves the production of semiconductor wafers containing multiple chips, followed by back-end manufacturing where the wafers are diced up into separate chips, packaged using protective materials, and tested. Furthermore, the three different steps of the semiconductor production process require access to a large quantity of different tools, machines and materials, some important examples of which are software and intellectual property for chip design, lithography machines and polysilicon for front-end manufacturing, and organic substrates and encapsulation resins for back-end manufacturing. Moreover, research and development (R&D) is important for all parts of the production chain, not least for chip design and for basic research, e.g. to develop new materials.[16]

Modern semiconductor components mainly consist of different types of integrated circuits, i.e. chips. One way to categorise them is according to three categories: logic, memory, and discrete/analogue/other (DAO). A simplified way of describing their respective functions is the following: logic chips, such as microprocessors and microcontrollers, perform calculations; memory chips, mainly DRAM and NAND, store data; and DAO semiconductors, for example transistors, sensors, optoelectronics and radio frequency semiconductors, transmit and transform information. Even though logic represents the largest semiconductor category in terms of revenues, most electronics contain a combination of both logic, memory and DAO.[17]

Furthermore, chip manufacturing is popularly categorised in terms of nanometers and process nodes, as a way to distinguish between advanced and less-advanced manufacturing capacity. In short, a process node of a certain nanometer size refers to the size of the transistors that together form a chip. The more transistors that fit on a single chip, the more powerful the chip. Advanced chips, especially logic and memory, are thus associated with smaller process nodes (often <10 nanometers).[18] However, even though nanometer size is a popular proxy for the degree of advancement in chip manufacturing, it does not follow that less-advanced chip manufacturing is insignificant. Process node size is not equivalent to chip utility, as different types of modern electronics and applications include chips from a variety of different process nodes. This is true not only for civilian goods, but perhaps more so for the defence sector. Even though certain new technologies, such as military-use AI, depend on state-of-the-art chip manufacturing, a large share of electronic components used in military applications are manufactured in less-advanced process nodes.[19] Legacy chips, manufactured in 28 nanometer process nodes or larger, can thus be of equal importance to

13 Miller, *Chip War*, 198, 239–40, 247–54, 291.

14 Ondrej Burkacky, Taeyoung Kim, and Inji Yeom, "Advanced chip packaging: How manufacturers can play to win," McKinsey & Company, 24 May, 2023, https://www.mckinsey.com/industries/semiconductors/our-insights/advanced-chip-packaging-how-manufacturers-can-play-to-win; Miller, *Chip War*, 217–8, 230, 250, 277–9, 349–50.

15 Front-end manufacturing is also known as wafer fabrication, and back-end manufacturing as assembly, testing and packaging (ATP).

16 Antonio Varas, Raj Varadarajan, Jimmy Goodrich, and Falan Yinug, *Strengthening the Global Semiconductor Supply Chain in an Uncertain Era* (Boston Consulting Group and Semiconductor Industry Association, 2021), 13–22, https://www.semiconductors.org/strengthening-the-global-semiconductor-supply-chain-in-an-uncertain-era/.

17 Varas et al., *Strengthening the Global Semiconductor Supply Chain,* 9–10.

18 Varas et al., *Strengthening the Global Semiconductor Supply Chain*, 17–8.

19 See for example Jared Mondschein, Jonathan W. Welburn, and Daniel Gonzales, *Securing the Microelectronics Supply Chain: Four Policy Issues for the U.S. Department of Defense to Consider* (RAND Corporation, 2022), 5–6, https://www.rand.org/pubs/perspectives/PEA1394-1.html.

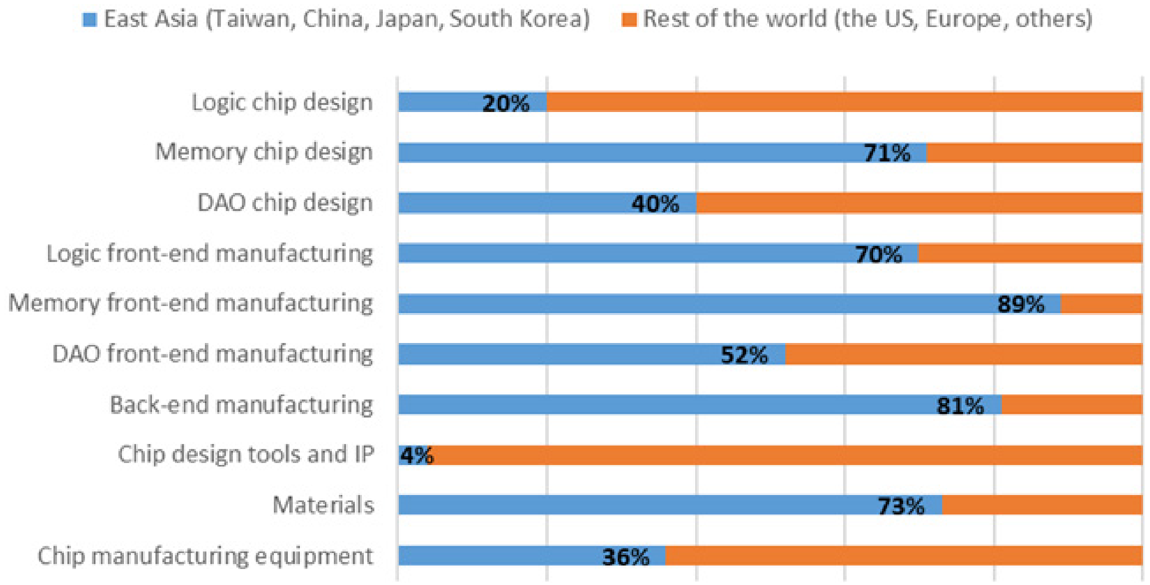

Figure 1. The East Asian semiconductor industry, *market share for each supply chain segment*, 2019.
Source: Varas et al., *Strengthening the Global Semiconductor Supply Chain*. **Note:** "Chip design tools" herein refers to Electronic Design Automation (EDA).

the most advanced chips.[20] The utility of less-advanced chips has been illustrated by reports of Russia harvesting refrigerators and dishwashers, imported from Kazakhstan, to cover some of its microelectronics supply needs during the on-going war against Ukraine.[21]

Figure 1 shows that East Asia represents the lion's share of global front-end and back-end chip manufacturing, as well as a considerable share of chip design and various inputs to chip manufacturing. In East Asia, as is the case in the rest of the world, semiconductor companies tend to specialise in specific parts of the value chain. Fabless companies focus solely on chip design and outsource manufacturing, whereas foundry companies and Outsourced Assembly & Testing (OSAT) companies specialise in front-end and back-end manufacturing respectively. However, some companies, known as Integrated Device Manufacturers (IDMs), cover both chip design and manufacturing in-house.[22] The history of the semiconductor industry suggests that not only companies but also countries specialise. The following sections provide overviews of each of the semiconductor industries of Taiwan, China, Japan and South Korea.

Taiwan

In 2019, more than 90 percent of the most advanced logic chip front-end manufacturing, in <10 nm nodes, took place at TSMC's fabs in Taiwan. Beyond being home to the leading chip foundry, Taiwan represents a significant portion of global front-end manufacturing (20 percent, with a higher share for logic chips), back-end manufacturing (27 percent), and raw material supply (22 percent).[23] Major Taiwanese semiconductor companies include foundry companies TSMC and United Microelectronics Corp. (UMC), fabless companies MediaTek and Realtek Semiconductor, and OSAT company ASE Technology Holdings (ASE Group).[24]

China

In 2019, Chinese companies represented a large portion (38 percent) of global back-end chip manufacturing capacity. Moreover, China represented 16 percent of global front-end chip manufacturing, but with very limited representation in the most advanced process nodes. China also stood for 16 percent of global raw material supply. It is notable that China is a leading

20 Sujal Shivakumar, Charles Wessner, and Thomas Howell, *The Strategic Importance of Legacy Chips* (Washington, DC: Center for Strategic and International Studies, March 2023), 1, https://www.csis.org/analysis/strategic-importance-legacy-chips.

21 Eric Tegler, "Is Russia Really Buying Home Appliances To Harvest Computer Chips For Ukraine-Bound Weapons Systems?" *Forbes*, 20 January, 2023, https://www.forbes.com/sites/erictegler/2023/01/20/is-russia-really-buying-home-appliances-to-harvest-computer-chips-for-ukraine-bound-weapons-systems/.

22 Varas et al., *Strengthening the Global Semiconductor Supply Chain*, 5, 24, 35.

23 Varas et al., *Strengthening the Global Semiconductor Supply Chain,* 31, 35.

24 Shu-Ching Jean Chen, "Meet Taiwan's Little-Known But Elite Semiconductor Makers," *Forbes*, 28 August, 2023, https://www.forbes.com/sites/shuchingjeanchen/2023/08/28/meet-taiwans-little-known-but-elite-semiconductor-makers/.

FOI
Swedish Defence Research Agency
SE-164 90 Stockholm
Tel: +46 8 5550 3000
www.foi.se

global supplier of many critical inputs to the semiconductor industry, in terms of metals and minerals such as germanium, tungsten, as well as various rare earth elements. China is also important due to the role of the Chinese market as a huge source of chip demand. In 2019, a third of global sales of semiconductors went to China. Through companies such as Huawei, Lenovo and Xiaomi, China represents a large share of global production of consumer electronics, such as smartphones and computers, with both domestic and international consumers.[25] Major Chinese semiconductor companies include foundry companies SMIC and Hua Hong Semiconductor, fabless company HiSilicon (a subsidiary of Huawei), the NAND and DRAM memory chip IDMs Yangtze Memory Technologies Corp (YMTC) and ChangXin Memory Technologies (CXMT), and OSAT company Jiangsu Changjiang Electronics Technology (JCET).[26]

Japan

In 2019, Japan represented some 20-30 percent of global front-end manufacturing capacity in the memory chip and DAO chip segments, as well as a minor share in the logic chip segment. Notable Japanese chip manufacturing companies include Kioxia and Renesas Electronics. However, Japan's major role within the semiconductor industry is that of being a supplier of certain advanced materials and equipment necessary for front-end chip manufacturing. Notably, Japan provides a large share of global supply of various gases and chemicals, as well as a near-monopoly (90 percent) on photoresist processing equipment.[27] Some of the key semiconductor companies in Japan are photoresist processing equipment supplier Tokyo Electron (TEL), photoresist suppliers Tokyo Ohka Kogyo and Shin-Etsu Chemical, silicon wafer supplier Shin-Etsu Handotai, and polycrystalline silicon supplier Tokuyama. Moreover, the Japanese multinational conglomerate SoftBank owns UK-based Arm, a key global supplier of core IP for chip design.[28]

South Korea

In 2019, almost half (44 percent) of global front-end manufacturing of memory chips took place in South Korea. Moreover, 8 percent of <10 nanometer logic chip front-end manufacturing is done in South Korea, and Samsung is one of three companies in the world, alongside TSMC and Intel, with the capacity to manufacture the most advanced logic chips. Furthermore, South Korea represents 59 percent of global memory chip design, and some 16 and 11 percent of raw material supply and back-end chip manufacturing respectively. The most significant South Korean semiconductor companies are the memory chip IDMs Samsung and SK Hynix.[29]

Important countries outside of East Asia

There are certain countries and actors outside East Asia that also demand mention. The US remains the global leader within chip design, and US companies have a strong market position within both chip design software and chip design itself. Moreover, US companies are leading within production of various tools and machines necessary for chip manufacturing. The Netherlands is also an important actor within the semiconductor industry, as the Dutch company ASML has a monopoly on advanced EUV lithography machines necessary for state-of-the-art chip manufacturing. Furthermore, chip design architecture provided by Arm puts the UK on the semiconductor map, even though Arm is Japanese-owned.[30]

Supply chain risks: nature, war and international economic rivalry

The high degree of internationalisation and specialisation within the semiconductor industry implies supply chain interdependencies, not only on a company-level but also between countries. This is certainly the case for the East Asian countries and their industries. Semiconductor-related trade flows between Japan, China, South Korea and Taiwan signify important expenses and revenues for the companies involved, as well as significant shares of GDPs.

25 Varas et al., *Strengthening the Global Semiconductor Supply Chain,* 12, 35.

26 Arran Hope, "China's top 10 semiconductor firms," The China Project*,* 3 February, 2023, https://thechinaproject.com/2023/02/03/chinas-top-10-semiconductor-firms/; Miller, *Chip War,* 319; OECD, *Measuring distortions in international markets: The semiconductor value chain*, OECD Trade Policy Papers No. 234 (Organisation for Economic Co-operation and Development, December 2019), 57–8, *https://one.oecd.org/document/TAD/TC(2019)9/FINAL/En/pdf*; Douglas B. Fuller, *Tech War or Phony War? America's Porous Controls on Semiconductor Fabrication Equipment and China's Response*, Winter 2023 Issue 78 (China Leadership Monitor, December 2023), 8, https://www.prcleader.org/post/tech-war-or-phony-war-america-s-porous-controls-on-semiconductor-equipment-and-china-s-response.

27 Varas et al., *Strengthening the Global Semiconductor Supply Chain*, 17, 20, 24, 35, 39, 41–2.

28 John Lee and Jan-Peter Kleinhans, *Mapping China's semiconductor ecosystem in global context: Strategic Dimensions and Conclusions* (Stiftung Neue Verantwortung and Mercator Institute for China Studies, June 2021), 30–1, 41, 45, 49, *h*ttps://merics.org/sites/default/files/2021-06/China%E2%80%99s%20Semiconductor%20Ecosystem_0.pdf.

29 Varas et al., *Strengthening the Global Semiconductor Supply Chain*, 24, 31, 35.

30 Varas et al., *Strengthening the Global Semiconductor Supply Chain,* 19, 31, 39, 41.

However, there is arguably an on-going shift away from current supply chain structures towards new ones. Among other things, this shift takes the shape of increased geographical diversification for advanced chip manufacturing, exemplified by Samsung and TSMC building new factories in the US, Japan and the EU.[31]

Force majeure: natural disasters, pandemics and wars

It is an inconvenient circumstance that much of crucial chip manufacturing capacity is currently concentrated in neighbouring countries in the Western Pacific Ocean, an area prone to natural disasters such as earthquakes (including tsunamis) and typhoons. Production stops in key chip factories due to natural disasters can have immense repercussions for global chip supply. The risk of single points of failure with global repercussions provides part of the rationale behind the on-going spread of manufacturing sites.[32]

Recent global crises have also shed light on supply chain vulnerabilities related to overreliance on individual suppliers for certain goods. The semiconductor industry is characterised by high market concentration for various crucial inputs throughout the supply chain, and semiconductor companies often strongly base their production process on certain specific materials, tools and equipment, as well as spare parts thereof, from specific suppliers. If access to a certain supplier and input is lost, it can take months to adjust. Even though companies might keep larger inventories for certain goods as a preemptive measure, safety stocks are never infinite.[33]

Geoeconomics: US-China rivalry and semiconductor export controls

The on-going shift in supply chain structures is also significantly shaped by geopolitical considerations. The background to this is that some supply chain disruptions are due to inter-state rivalries, rather than natural disasters and fragile logistics. During the past couple of decades, geoeconomic policy instruments have targeted semiconductor supply chains in East Asia, as a means for various states to punish or stifle the technological progress of geopolitical opponents. Arguably, the most important actor in this regard is located outside of the region. In recent years, the US has implemented a variety of measures that have affected economic exchange between US companies, China's tech industry, and third country companies. Notably, since 2019 the US has made efforts to limit the chip supply for Chinese telecom giant Huawei. It started out with export controls for US companies, but thereafter expanded to prohibiting third country chip manufacturers, e.g. in Taiwan, using US-produced equipment from having Huawei as a customer. The strong market position of the US for the production of tools and machines necessary for chip design and manufacturing gives the US the possibility to exert pressure on dependent states and companies.[34]

The export controls thus initially targeted an end producer of electronic products, downstream from the semiconductor industry. Thereafter, companies upstream in the Chinese semiconductor industry have been targeted, including the foundry company SMIC. However, the results of US sanctions against the Chinese semiconductor industry have been mixed. Initial export controls against Huawei were circumvented through transshipments and off-the-shelf sales, whereas the prohibitions related to chip manufacturing using US equipment seem to have had a greater impact.[35] There are further indications that US sanctions against China have failed with their purpose. In September 2023, Huawei showcased a new smartphone with a processor based on 7 nm technology, manufactured by SMIC using ASML equipment imported prior to US sanctions coming into effect.[36] Moreover, US export controls are mainly focused on advanced technology, while the export of less advanced chips to China is unchecked. Some companies even benefit from being in between the US-China trade war, due both to increased customer demand for chips produced outside of China, as well as increased demand in China for chips not covered by US export controls.[37] In October 2023, the US revised its export controls in the light of criticism regarding the lack of precision and recent successes by SMIC and Huawei. The new export controls are supposed to be narrower, but are still characterised by significant gaps. For instance, manufacturing equipment could still be legally exported to certain Chinese or third-country companies in China, whereupon potential ownership changes are beyond the control of the US.[38]

31 Yongwook Ryu, Lee Kuan Yew School of Public Policy, Singapore, online interview by author, 23 October, 2023.

32 Varas et al., *Strengthening the Global Semiconductor Supply Chain,* 40.

33 A representative of the Taiwanese semiconductor industry, interview by author, Hsinchu, Taiwan, 3 July, 2023.

34 Agathe Demarais, *Backfire: How Sanctions Reshape the World Against U.S. Interests* (New York: Columbia University Press, 2022), 169–70.

35 Demarais, *Backfire,* 169–70.

36 Debby Wu, "US Can't Halt SMIC, Huawei's Tech Advances, Chip Guru Says," *Bloomberg*, 27 October, 2023, https://www.bloomberg.com/news/articles/2023-10-27/us-can-t-halt-smic-huawei-s-chip-advances-industry-guru-says#xj4y7vzkg.

37 Representatives of the Taiwanese semiconductor industry, interviews by author, Hsinchu and Taipei, Taiwan, 3–4 July, 2023.

38 Fuller, *Tech War or Phony War?*, 11.

The US has also proved willing and capable of influencing the decision-making of other states in order to stifle China's ambitions to develop its semiconductor industry. This has taken the shape of US pressure against equipment suppliers, stifling China's access to key inputs for chip manufacturing. In 2018, the US under the Trump administration exercised pressure against the Dutch government in order to prevent the sale of EUV lithography machines from ASML to SMIC. These machines are classified as dual-use technologies, which means an export license is required. Moreover, ASML machines are dependent on parts from US companies, which gives the US leverage over export decisions. In the end, the Dutch government did not approve an export license for ASML.[39] US pressures against the Netherlands and ASML have continued during the Biden administration. Export restrictions for lithography machines other than EUV have also been implemented.[40] Moreover, Japan, which like ASML has a monopoly-like position for certain chip manufacturing equipment, has also proved willing to implement export controls on various equipment. However, unlike the US, Japan seems hesitant to target China specifically.[41]

China also has some ability to employ offensive geoeconomic measures, largely tied to its position as a leading supplier of various critical raw materials for tech supply chains, including for the semiconductor industry. A fresh example of this is from July 2023, when China announced upcoming export controls on gallium and germanium. However, even though the export controls serve to display China's displeasure against being the target of a US-led sanctions regime, the potential impact of these export controls seems debatable. For instance, Japan is not wholly dependent on China for imports of critical metals and minerals. In fact, Japan has made efforts to reduce its dependency on China for more than a decade, not least when it comes to rare-earth elements. In 2018, Japan imported 58 percent of rare earths from China, compared to 85 percent in 2009.[42]

Geopolitical rivalry in East Asia is dominated by the broader US-China great power competition. However, there has also been a diplomatic spat between South Korea and Japan, two US allies. Between 2019 and early 2023, there was a trade dispute between the two East Asian neighbours, with spill-over effects on the semiconductor industry. For example, Japan utilised its position as a key supplier of certain chemicals, as it imposed export controls on not least photoresist and hydrogen fluoride, both of which are vital inputs for South Korea's chip manufacturers.[43] In the end, shared concerns in South Korea and Japan regarding regional security, in terms of the threats posed by North Korea and China, seem to have overcome political disagreement.

The supply chain for semiconductors in East Asia has been a frequent target of geoeconomic measures. Beside the export controls described above, tightened foreign investment screening is another example. Results have varied, which also depends on the reach of US sanctions, or lack thereof. For the US to exercise significant power over China's access to certain chips or chip manufacturing inputs, it needs to control overall supply, whether through its own companies or through its role as a key upstream supplier to dominant suppliers. For instance, the US probably has more power over China's access to chips manufactured using US equipment than China's access to silicon wafers. The production of silicon wafers largely takes place in Japan, South Korea and Taiwan, and does not seem to be overly dependent on upstream supplies from the US.[44] However, the US could possibly influence East Asian governments that in turn can exercise power over key wafer suppliers and stop exports to China. At the same time, Japan, South Korea and Taiwan, all of which have formal or informal security ties to the US, are not always enthusiastic about adhering to broad-brush US sanctions regimes. Moreover, China's strong position within certain supply chain segments, such as back-end manufacturing, provides it with some protection against geoeconomics, at least to the extent that the

39 Noah Barkin, *Export controls and the US-China tech war: Policy challenges for Europe* (Berlin, Germany: Mercator Institute for China Studies, March 2020), 8, *https://merics.org/en/report/export-controls-and-us-china-tech-war*; Tim Kelly, Karen Freifeld, and Kentaro Sugiyama, "As Japan aligns with U.S. chip curbs on China, some in Tokyo feel uneasy," *Reuters*, 24 July, 2023, https://www.reuters.com/technology/space/japan-aligns-with-us-chip-curbs-china-some-tokyo-feel-uneasy-2023-07-24/.

40 Cagan Koc, Ian King, and Jillian Deutsch, "ASML, Europe's most valuable tech firm, is at the heart of the U.S.-China chip war," *Bloomberg*, 27 April, 2023, https://www.bloomberg.com/news/articles/2023-04-26/asml-europe-s-most-valuable-tech-firm-to-define-us-china-chip-war.

41 Kelly et al., "As Japan aligns with U.S. chip curbs".

42 Nicolas Velez, "How Will China's Rare Earth Export Controls Impact Japan?" *The Diplomat*, 18 August, 2023, *https://thediplomat.com/2023/08/how-will-chinas-rare-earth-export-controls-impact-japan/*; Jane Nakano, *The Geopolitics of Critical Minerals Supply Chains* (Washington, DC: Center for Strategic and International Studies, March 2021), 20–1, https://csis-website-prod.s3.amazonaws.com/s3fs-public/publication/210311_Nakano_Critical_Minerals.pdf

43 Kim Tong-Hyung, "South Korea restores Japan on trade 'white list'," *AP News*, 24 April, 2023, *h*ttps://apnews.com/article/korea-japan-trade-exports-russia-9c3707521e77a3717a664557d90531b4.

44 Lee and Kleinhans, *Mapping China's semiconductor ecosystem*, 49-51.

supply chains of the US or its allies are dependent on Chinese OSAT companies.

Recent geoeconomic conflict in East Asia related to the semiconductor industry has largely taken place within the context of the US-China great power competition. This is also part of the context for the on-going realignment of international semiconductor supply chains, discussed below.

Industrial policy and the realignment of semiconductor supply chains

The state has been a key actor in the East Asian semiconductor industry. The establishment of leading semiconductor companies in Japan, South Korea, Taiwan and China was aided by various kinds of state support. In the 21st century, the semiconductor industry continues to receive special state attention the world over. The semiconductor industry is increasingly regarded as a sector of the economy of particular strategic importance, not unlike the defence industry to which a portion of produced chips flow. In the light of US-China great power competition and increased securitisation of supply chains, there are many state actors across the world that actively promote the development of their semiconductor industries. These efforts include industrial policy, i.e. state support targeting the semiconductor industry.[45]

Industrial policy initiatives across the globe

The East Asian states, the US, as well as the EU are all currently promoting the development of their semiconductor industries through state support. First of all, China's economic and political support for its semiconductor industry is exceptional from an international perspective. It is not least a key part of China's *Made in China 2025*, the vast multisectoral industrial policy initiative announced in 2015. Japan, South Korea, and Taiwan have also recently implemented or renewed industrial policy initiatives for the semiconductor industry.[46] As of 2022, the US has its own industrial policy program for the semiconductor industry, called the CHIPS and Science Act.[47] Moreover, the EU has similarly implemented the European Chips Act, which came into effect in September 2023.[48] Through a variety of programs and measures, the US, the EU and the East Asian states seek to incentivise investments in order to achieve higher chip self-sufficiency and to lead in technological competition. Besides providing economic incentives such as subsidies for manufacturing and R&D, the different policy initiatives to varying degrees include incentives for private investments, fostering human capital and creating regional innovation hubs, among other things. An explicit purpose of the European Chips Act is also to "promote international partnerships with like-minded countries."[49] International partnerships are important for all countries, but the EU's relatively weak position in the overall semiconductor supply chain bears emphasis.[50] As for the motivations behind recent industrial policy initiatives, perceived risks of chip supply shortages and international supply chain dependencies involving geopolitical rivals are commonly emphasised. Moreover, in the US and the EU, recent industrial policy initiatives are partly intended to promote fair competition vis-à-vis East Asia, a region where economically competitive chip manufacturing is in part explained by state support. In a sense, subsidies in the US and the EU are used to fight the effect of subsidies elsewhere.

To the extent that on-going state-led industrial policy initiatives across the globe achieve their stated goals, the aggregated result should have considerable implications for the future structure of semiconductor supply chains. However, it seems highly unlikely that individual countries

45 Industrial policy can be regarded as a geoeconomic measure, when industrial policy is an economic means not only to increase domestic self-sufficiency, but also to get ahead in inter-state technological competition.

46 Japan released a new semiconductor strategy as recently as July 2023, see METI, 半導体・デジタル産業戦略 [Semiconductor and Digital Industry Strategy] (Tokyo, Japan: Ministry of Economy, Trade and Industry, August 2023), https://www.meti.go.jp/press/2023/06/20230606003/20230606003-1.pdf; in early 2023, South Korea implemented the so-called K-Chips Act, which in practice meant a law was amended to incentivise semiconductor industry investments, see Jo He-Rim, "Korean chips act aims to extend tax cuts for local chipmakers," *Korea Herald*, 30 March, 2023, https://www.koreaherald.com/view.php?ud=20230330000782; and as for Taiwan, the semiconductor industry is a key focus in the Six Core Strategic Industries program promoted by president Tsai Ing-wen since 2020, see "Program for Promoting Six Core Strategic Industries," National Development Council, accessed 31 October, 2023, https://www.ndc.gov.tw/en/Content_List.aspx?n=2D827BFE7E3598BE.

47 "FACT SHEET: CHIPS and Science Act Will Lower Costs, Create Jobs, Strengthen Supply Chains, and Counter China," The White House, 9 August, 2022, https://www.whitehouse.gov/briefing-room/statements-releases/2022/08/09/fact-sheet-chips-and-science-act-will-lower-costs-create-jobs-strengthen-supply-chains-and-counter-china/. CHIPS is an acronym for Creating Helpful Incentives to Produce Semiconductors.

48 "European Chips Act," European Commission, accessed 31 October, 2023, https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-chips-act_en.

49 European Commission, "European Chips Act."

50 The EU-US Trade and Technology Council, instituted in 2021, is an example of a forum for semiconductor cooperation, see "EU-US Trade and Technology Council," European Commission, accessed 16 December, 2023, https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/stronger-europe-world/eu-us-trade-and-technology-council_en.

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or regions will be able to achieve a high degree of chip self-sufficiency, even in the long term. Each part of the complex production process requires inputs from a myriad of subcontractors, spread out across the world. An illustration of this is ASML's supply chain for EUV lithography machines, containing approximately 100 000 parts from 5 000 different suppliers.[51] It is worth noting that ASML's original success in establishing itself as a leading manufacturer of EUV equipment in the 1980s was partly based on the company's ability to "assemble systems from components meticulously sourced from suppliers around the world". Meanwhile, its Japanese rivals, Canon and Nikon, tried and failed to achieve self-sufficient manufacturing of lithography tools.[52]

Barriers to entry: financial and human capital, time, ecosystems and first-mover advantage

There are various barriers to entry into the semiconductor industry, some of which are easier to overcome than others, associated with increasing self-sufficiency in different parts of the supply chain. The capital investments necessary to establish a new state-of-the-art foundry for logic or memory chips, up to par with those of TSMC or Samsung, can amount to tens of billions of US dollars. Meanwhile, getting ahead in chip design demands substantial R&D investments.[53] Even in cases where the financial means are available, through extensive state subsidies or otherwise, it can take many years to achieve production capacity and technological prowess comparable to that which current leading semiconductor actors have spent decades honing. For example, the ambitions of SMIC in the early 2000s to achieve international competitiveness through imported expertise from Taiwan shed light on the value of access to the proper personnel. Furthermore, to obtain advanced chip manufacturing capacity with cost- and time-efficient operations requires an entire ecosystem. An example of this is that the import of advanced machines used in the manufacturing process can at times require access to specialised transports. Moreover, it can be of vital importance to have the machine suppliers establish local offices to provide swift technical support.[54]

Furthermore, end-product manufacturers, i.e. companies that assemble and sell electronic products using chips from the semiconductor industry, are a crucial part of the ecosystem. For example, synergies between Taiwan's semiconductor industry and its electronics industry and broader IT sector contributed to the island's dominant position in the semiconductor industry.[55] In general, local synergies and reliable partnerships are indispensable, but can take a long time to develop and bear fruit. Another example is provided by the long-running partnership between ASML and TSMC, which have both gradually evolved from small actors in the 1980s to semiconductor giants some decades later.[56] First-mover advantages should not be underestimated. For example, equipment suppliers can cement their market position through established partnerships. This can take the shape of leveraging data collected from factories using their equipment, to facilitate further quality improvements and competitiveness. Such advantages are out of reach for newly established companies.[57]

State subsidies can be useful to brute force certain industrial development, especially for capital investments. The historical background of the East Asian semiconductor industry illustrates this fact, even though other success factors include international support and cooperation, often involving the US and Silicon Valley. Relevant concerns can also be raised regarding the market distorting effects and long-term economic sustainability of certain types of state support. For instance, there are risks associated with excessive investments from the state that are detached from the companies' market profitability. Japan's failure in maintaining its hold on the DRAM market in the 1990s serves as a warning example in this regard. Another example is provided by China's persistent struggles with developing its semiconductor industry, despite extensive state subsidies during the past decade as well as historically.

Comparative advantages: specialisation, labour costs, culture and laws

Comparative advantages are also a factor to consider. For example, the success of TSMC and its foundry model suggest that economies of scale are easier to achieve for specialised production. By contrast, Intel tried and failed with its

51 Varas et al., *Strengthening the Global Semiconductor Supply Chain,* 29-30.

52 Miller, *Chip War*, 185–6.

53 Varas et al., *Strengthening the Global Semiconductor Supply Chain*, 18, 24–5.

54 A representative of the Taiwanese semiconductor industry, interview by author, Hsinchu, Taiwan, 3 July, 2023.

55 Kristy Tsun Tzu Hsu, *Taiwan as a Partner in the U.S. Semiconductor Supply Chain* (Washington, DC: Wilson Center, September 2022), 6, https://www.wilsoncenter.org/sites/default/files/media/uploads/documents/2022-09_Taiwan_SemiconductorSupplyChain_Hsu.pdf.

56 Miller, *Chip War*, 186.

57 Fuller, *Tech War or Phony War?*, 9.

ambitions of simultaneously being the leading foundry and chip designer.[58] Moreover, some comparative advantages can be difficult to overcome. For example, not all countries with semiconductor ambitions have access to substantial domestic or regional deposits of crucial metals and minerals. Another example relates to labour power. China's large share of global back-end manufacturing capacity is in part explained by its access to cheap labour for this labour-intensive part of the manufacturing process.[59] Company culture can also be an important component. For example, many East Asian semiconductor companies have employees that are used to being available around the clock, which can be a success factor for production that might require constant attention from personnel with specific expertise. Work ethics and views on work-life balance are difficult to export to countries with laxer working conditions, which might pose an obstacle to successful geographical diversification of manufacturing capacity.[60] Differences in international competitiveness for labour-intensive production is also a reflection of different countries having different labour laws and regulations.[61]

Future developments

Re-shaping current supply chain dependencies is thus associated with various difficulties. However, international ambitions to achieve chip self-sufficiency with a geopolitical touch are likely to continue. The outcome is uncertain; it would seem that there is at best potential for a Western-oriented semiconductor supply chain including the US, key European countries, Japan, South Korea, and Taiwan, that would exclude China. The focus will probably remain on decreased exposure to China, using means such as export controls and industrial policy. Many of these efforts specifically target supply chains for advanced chip manufacturing. At the same time, a US-led coalition intent on stifling Chinese ambitions must deal with risks of losing access to Chinese raw materials, back-end chip manufacturing capacity, and a vast market for chips. Moreover, many leading semiconductor companies in, for example, South Korea and Taiwan have sunk costs in China, not least in terms of significant fab investments. It also remains to be seen how long China will accept being at the receiving end of a US-led geoeconomic coalition without taking more forceful countermeasures.

However, China also contributes to supply chain realignments, as China's own efforts aimed at increasing its semiconductor self-sufficiency and decreasing its vulnerability to foreign geoeconomics imply a partial decoupling from international supply chains.[62] Regardless, given the rise of an anti-China coalition and consequently further limits in China's access to advanced semiconductor inputs, China's prospects of leapfrogging its semiconductor industry past its competitors would seem to depend on disruptive developments. One example would be if China were to successfully establish a lead within compound semiconductors, i.e. chip manufacturing based on multiple semiconductor materials, for example silicon-carbide or gallium-nitride.[63] Another potential path for China would be if it managed to establish a strong market position in specific market segments that could give it new leverage over actors upstream and downstream in the international semiconductor supply chain. For example, Wuhan-based YMTC might have the potential to dominate the manufacturing of advanced NAND memory chips. Moreover, current attempts from Chinese companies to break free from dependence on Western-sourced intellectual property for chip design architectures are also noteworthy, as it might have implications for China's resilience against foreign sanctions and possibilities to develop a parallel semiconductor ecosystem.[64]

Furthermore, export controls against China might backfire and in some ways benefit the long-term prospects of the Chinese semiconductor industry. An example of this is provided by Chinese companies producing chip manufacturing equipment, a supply chain segment in which China's share of the global market is very limited. Such companies have sometimes claimed greater domestic market shares, and potentially increased their prospects for international competitiveness, once foreign companies were prohibited from supplying the Chinese market.[65] Nevertheless, China will still have significant troubles achieving a high degree of chip self-sufficiency by itself, if it also wants to remain ahead in the development of advanced technologies. It is likely to

58 Miller, *Chip War*, 236, 239.

59 Varas et al., *Strengthening the Global Semiconductor Supply Chain*, 35.

60 A representative of the Taiwanese semiconductor industry, interview by author, Hsinchu, Taiwan, 3 July, 2023.

61 Hsu, *Taiwan as a Partner*, 13.

62 Yongwook Ryu, Lee Kuan Yew School of Public Policy, Singapore, online interview by author, 23 October, 2023.

63 See for example NATO, *Science & Technology Trends 2023-2043: Across the Physical, Biological and Information Domains, Volume 2: Analysis* (NATO Science & Technology Organization, March 2023), 101, https://www.nato.int/nato_static_fl2014/assets/pdf/2023/3/pdf/stt23-vol2.pdf.

64 Miller, *Chip War*, 185–6. YMTC has been one of the Chinese semiconductor companies specifically targeted by US sanctions.

65 Fuller, *Tech War or Phony War?*, 6–7.

continue being subject to offensive geoeconomic measures, limiting its access to international supply chains for advanced chip manufacturing. If China were to succeed in annexing Taiwan and the island's advanced semiconductor manufacturing capacity, this would of course change things, and have far-reaching implications for US-China tech rivalry. However, China would then risk being the target of broader US-led export controls and losing access to further crucial inputs to its industry.[66]

There is broad consensus within the US-oriented camp regarding the geopolitical threat posed by China and the close relation between the semiconductor industry and national security. However, there is also potential for economic conflict. They might not be able to uphold a united front against as China, seeing as the rationale for economic security is not the same as for military defence. Military alliances are premised on the collective rescue of distraught members, whereas in matters of economic security, "an attack on one country is an opportunity for another country". In other words, declines in economic relations between two countries can entail new economic opportunities for third party countries.[67] For instance, a reduction of trade and investments between the US and China might in some cases provide Japanese, Taiwanese and South Korean companies with new opportunities to expand in both the US and China.

Even though the US can exert influence on its allies, through export controls and other means, legislation pertaining to economic exchange with China is ultimately up to national governments to decide. Each party in the US-oriented camp will probably want to maximise the utility of its own semiconductor industry for geoeconomic purposes, to the extent that there are economic and national security benefits, while also minimising the risk of countermeasures or second-order effects that would hurt its economy. For instance, broad and imprecise sanctions can be damaging for the sanctioning country's own industry and come with costs that outweigh the benefits. Moreover, international cooperation is a feature of current semiconductor ambitions in the US, the EU, Japan, Taiwan and South Korea, but the industrial policy efforts of each are nevertheless largely aimed at increasing self-sufficiency, planting seeds for contradictory interests now or in the future. To conclude, there is thus potential for both collaboration and conflicts within the US-oriented camp when it comes to balancing economic interests and national security with regards to China and the semiconductor industry.

Implications for Sweden and its defence sector

Future developments related to the semiconductor industry in East Asia will affect both the Swedish state and society. Swedish civilian industries such as automotive and telecom rely on international supply chains for chips. The same is true for the defence sector, including the Swedish defence industry and industrial associations, as well as the government agencies associated with Sweden's military and civil defence. The shape of Swedish supply chain dependencies for chips are not necessarily obvious judging by first tier suppliers in, e.g., the US or Europe. Suppliers tend to have suppliers of their own, and supply chains for finished chips, but also for various crucial inputs in terms of materials, machines and tools, eventually lead to East Asia. The issues touched on in this memo, not least supply chain risks and industrial policy initiatives, are important considerations for Swedish and EU national security moving forward. The following are some questions of special relevance to the Swedish defence sector:

- To what extent is the Swedish defence sector aware of its semiconductor supply chain dependencies and vulnerabilities? What dependencies are there on specific manufacturers in specific countries?
- What are the Swedish defence sector's most significant semiconductor supply chain vulnerabilities toward China?
- What are the risks for the Swedish defence sector associated with China's potential to utilise its influence over the semiconductor supply chain for political purposes, for example in the area of critical raw materials?
- How will the EU's recent industrial policy initiative, the European Chips Act, affect the Swedish defence sector's semiconductor supply chain resilience?
- Are there semiconductor supply chain risks that are unique for Sweden?

66 See for example Bradley Martin, Laura H. Baldwin, Paul DeLuca, Natalia Henriquez Sanchez, Mark Hvizda, Colin D. Smith, and N. Peter Whitehead, *Supply Chain Interdependence and Geopolitical Vulnerability: The Case of Taiwan and High-End Semiconductors* (RAND Corporation, May 2023), https://www.rand.org/pubs/research_reports/RRA2354-1.html.

67 The distinction between rationale for military defense and economic security was provided by Kazuto Suzuki, International House of Japan, Tokyo, Japan, online interview by author, 31 October, 2023.

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