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The Economics of Chip War: China's Struggle to Develop the Semiconductor Industry

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This article highlights the U.S. government's measures to slow the development of the Chinese semiconductor industry and China's technological capabilities and institutional conditions, to fight back toward China's effort to achieve self-reliance in this industry.

China has set ambitious goals to increase its domestic semiconductor production. These goals are a part of a grander political vision: that the country will become a dominant technology power by 2049, the 100th anniversary of the People's Republic of China's founding.[1] Semiconductors have also been a target industry under the state-led industrial policy "Made in China 2025" initiative launched in 2015 by the Chinese government. This initiative aimed to increase the country's chip production from less than 10% of demand at the time to 40% in 2020 and 70% in 2025.[2]

However, China has been nowhere close to this goal yet. In 2022, China imported about 90% of its requirements in the chip industry.[3] China's semiconductor consumption accounts for more than three-quarters of the global total.[4] It produces only about 15% of global semiconductor output.[4] China annually spends more than US$400 billion in importing chips.[5]

The Chinese semiconductor industry has not been able to catch up with its global competitors, such as Taiwan, South Korea, and the United States. Some argue that China's chip equipment makers are 4 to 5 years behind their

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foreign counterparts.[4] Others suggest that the lag could be as long as a decade or two.[1]

Starting October 2022, a series of control measures have been taken by the U.S. government, which are intended to block Chinese chip makers' access to key resources.[6] These measures are aimed at limiting China's capability to design and manufacture advanced chips, as well as chip manufacturing equipment, domestically by blocking the country's access to United States-made chip design software, semiconductor manufacturing equipment, as well as United States-built components.[7] In some cases, particular Chinese companies are blacklisted.[8] The exact impacts of these measures upon the Chinese semiconductor industry are not fully known yet.

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In this article, we offer a detailed description of the U.S. government's measures to slow down the development of the Chinese semiconductor industry. It also critically looks into China's technological capabilities and the institutional context to counter the U.S. government's control measures.

RECENT UNITED STATES CONTROL MEASURES

Recently, the United States has been taking a series of control measures that are directed toward slowing down China's efforts to develop the high-end semiconductors required for artificial intelligence (AI) and supercomputing. In October 2022, new rules were announced that require U.S. companies, such as Nvidia and AMD, to stop supplying Chinese chipmakers with equipment that can produce advanced chips unless they obtain permission. Export controls have also been introduced to include some semiconductor production items.[4] Moreover, U.S. companies cannot engage in transactions with Chinese firms for some end-uses of certain types of integrated circuits or chips. Companies, such as Taiwan Semiconductor Manufacturing Co. Ltd. (TSMC), are prohibited from producing sophisticated microchips in China.[9] U.S. citizens and green-card holders are also banned from working on certain chip technology for Chinese entities.[4] The Commerce Department's Bureau of Industry and Security argued that China could use these chips to "produce advanced military systems," although the chips can also be used for civilian purposes.[9] Chinese firms cannot access advanced chips from non-Chinese factories that rely on U.S. technology to manufacture their products.[8]

Further control measures were implemented in December 2022. The U.S. Commerce Department's Bureau of Industry and Security added Chinese memory chipmaker Yangtze Memory Technologies Corp. (YMTC) and 21 other major companies in the AI chip sector to a trade blacklist, known as the *Entity List*. The measure blocked these companies' ability to purchase semiconductors and production tools made anywhere in the world using U.S. technology.[10]

In January 2023, after many years of lobbying from the United States, Japan, and The Netherlands agreed to tighten export restrictions of chip manufacturing equipment to Chinese companies.[11] By teaming up with and getting the support of these two countries, the United States hopes to effectively lock China out of key technology and equipment that are needed to build advanced chip-producing foundries (fabs). More than 90% of the global semiconductor manufacturing equipment market is controlled by the United States, The Netherlands, and Japan.[5]

Especially, the Dutch government's decision to impose new export controls on microchips manufacturing equipment to China is likely to have a detrimental effect on the Chinese semiconductor industry. This is because the Dutch developer and manufacturer of photolithography machines, Advanced Semiconductor Materials Lithography (ASML), dominates the global market for lithography, which involves using light to create certain patterns on silicon wafers.[12] In 2021, China was ASML's third largest market, after Taiwan and South Korea. ASML's sales revenue in China that year was 2.1 billion euros, which represented about 16% of global sales.[13]

A number of high-end chips are made using extreme ultraviolet (EUV) and deep ultraviolet (DUV) lithography machines. In 2020, ASML had 88% share in the DUV market.[14] ASML is the only company in the world to make EUV lithography machines. ASML sells such machines to semiconductor manufacturers at US$200 million a piece,[15] which are used to make the most advanced chips (for example, 3, 5, and 7 nm). These smallest nodes are used to develop AI systems, smartphones, cloud data centers, and self-driving cars. They are also used in some military applications.[16]

Initially, Dutch export controls to China only affected EUV machines. ASML has not exported EUV machines to China since 2019.[15] There are currently no EUV systems in China.[15]

The January 2023 agreement also targets older DUV machines that are used to make less advanced and larger process nodes, such as those used in automobiles, industrial equipment, and home appliances. These include 14-nm chips, 18-nm dynamic random-access memory chips used to make low-cost

and high-capacity computer memory, and NAND flash chips.[16]

In February 2023, the U.S. Department of Commerce called for applications for funds from the CHIPS and Science Act passed by Congress in 2022.[17] The CHIPS and Science Act has allocated a US$39 billion federal fund, which aims to bolster the development of the U.S. semiconductor industry. Chipmakers receiving money are prohibited to use the fund for projects outside the United States. They cannot build or significantly expand semiconductor manufacturing facilities in the "foreign entities of concern" for a decade.[18] Funded companies are also prohibited from conducting joint research or licensing technology from such entities. If a company violates these rules, the federal government can ask the company to return the money provided under the CHIPS and Science Act (Table 1).[19]

EFFECTS ON THE CHINESE SEMICONDUCTOR INDUSTRY

There are contradictory views regarding the long-term effects of the U.S. control measures on the Chinese semiconductor industry. One view is that more extensive bans on advanced chip exports to China could accelerate the timeline for indigenous Chinese firms to develop a domestic chip design ecosystem, and local semiconductor supply chains in the long run.[21] In support of this view, some have argued that the main reason why China's domestic AI chip design companies failed to gain market share in China is because they could not compete with U.S. chip manufacturers, such as Nvidia and AMD. Chinese chip makers got into the vicious circle because of the lack of enough customers to benefit from economies of scale and network effects, since Chinese companies were attracted to U.S. firms, such as Nvidia and AMD. The new U.S. export controls can help break this vicious circle. Revenues that flowed to U.S. companies will now go to Chinese chip companies, which can help them enjoy the economies of scale and develop their competitive advantage.[7]

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The opposite argument is that the U.S. government's control measures will slow down the development of the Chinese chip industry by forcing companies using U.S. technology to cut off support for China's chip factories and designers,[22] due to challenges, such as poorly defined and implemented strategic plans in the chip industry,

TABLE 1. Recent U.S. control measures to slow down the development of China's semiconductor industry.

Date	Action	Remarks
7 October 2022	New rules announced that prohibit U.S. companies to: 1) supply Chinese chipmakers with equipment that can produce advanced chips; 2) engage in transactions with Chinese firms for some end-uses of certain types of chips; 3) produce sophisticated microchips in China. U.S. citizens and green-card holders are banned from working on certain chip technology for Chinese entities.	The rules focus on limiting the development and production of advanced node semiconductors, semiconductor production equipment of any type, advanced computing capabilities, and supercomputers in China.[20]
15 December 2022	YMTC and 21 other Chinese companies added to the Entity List.[10]	The measure blocked these companies' access to semiconductors and tools made using U.S. technology.
27 January 2023	Japan and The Netherlands agreed to tighten export restrictions of chip manufacturing equipment to Chinese companies.[11]	It is expected to take many months for Japan and The Netherlands to "finalize legal arrangements."[11]
28 February 2023	Chipmakers receiving money under the CHIPS and Science Act re aprohibited: 1) to use the funds for projects outside the United States; 2) build or expand semiconductor manufacturing facilities in the "foreign entities of concern" for a decade; 3) conduct joint research or licensing technology from such entities.	Violators s can be asked to return the money.

corruption, and lack of human capital. Chinese technology firms are not in a strong position to develop chip-related advanced innovations on their own.[1] China-made chips are thus unsuitable to substitute for equipment lost from U.S. suppliers, such as KLA Corp., Applied Materials, and Lam Research.[4] Chinese chip manufacturers thus would face difficulty in catching up with their counterparts.

The following example could help illustrate the effect of the U.S. export control measures on the Chinese semiconductor industry. In October 2020, China's Semiconductor Manufacturing International Corporation (SMIC) was reported to develop a 7-nm process.[1] This is regarded as a watershed moment in chip manufacturing in China.[23] However, by that time, TSMC had already manufactured more than 1 billion 7-nm chips.[24] The unavailability of EUV technology meant that SMIC needed to use DUV technology, which added a high degree of complexity in the chip-design process. Consequently, SMIC's 7-nm chip manufactured by using DUV was estimated to cost about 10 times as high as a chip manufactured at TSMC's 7-nm node.[23] By preventing or limiting China's access to high-end chips, the U.S. control measures are thus likely to have an unfavorable impact on the development and deployment of next-generation technology, such as AI and supercomputing in the country.[7]

On the other hand, while a main goal of the U.S. export control measures is to prevent China's use of chips in advanced military applications,[9] some argue that the U.S. export controls are likely to have little effect on the People's Liberation Army (PLA). The PLA mostly relies on older and less-sophisticated chips.[25] The sales of U.S. technology for military applications have been banned for a long time.[21] However, the PLA was reported to rely on a number of intermediate and shell companies to purchase advanced AI chips that were designed by U.S. firms and manufactured in Taiwan and South Korea.[26]

> The CHIPS and Science Act has allocated a US$39 billion federal fund, which aims to bolster the development of the U.S. semiconductor industry.

CHINA'S TECHNOLOGICAL CAPABILITIES AND THE INSTITUTIONAL CONDUCIVENESS TO SUPPORT THE DEVELOPMENT OF THE LOCAL CHIP INDUSTRY

In the report of the 20th National Congress of the Chinese Communist Party (CCP), which was held from 16 to 22 October 2022, that is, after the October 2022 announcement of the U.S. semiconductor export controls, the CCP has expressed a determination to "realize high-level technology self-strength and self-independence."[27] In December 2022, China announced a support package of more than 1 trillion yuan (US$143 billion) over a 5-year period to develop its semiconductor industry. A significant part of the funding will be used to purchase domestic semiconductor equipment for fabs. Chinese companies will receive a subsidy of up to 20% on the cost of equipment and receive tax breaks for investing in assembly, packaging, and R&D of chips.[28] A key question, however, is whether China has technological capabilities and supportive institutional conditions to achieve such goals.

In general, China has demonstrated a poor track record in developing emerging technologies. The Chinese government's direct intervention to develop domestic technological capacities have failed in the past. A notable example is the attempt to make lithography equipment for chipmaking. The research in lithography started in 2006. Instead of industrial engineers, academics examined and verified homegrown lithography. The equipment was theoretically usable but could not be used in the fabs by any chip manufacturer.[29]

As another example, consider the secretive national semiconductor industry fund, popularly known as the *Big Fund*. The Big Fund was founded in 2014, which involves distributing funds to chipmakers. The shareholders of this public–private investment program include the finance ministry, China Development Bank, China Tobacco, and China Mobile. The Big Fund raised US$47 billion by 2022.[30]

Despite some successes, such as helping the growth of some established semiconductor firms (for example, YMTC and SMIC), the Big Fund was plagued by rampant corruption. The former head of the Ministry of Industry and Information Technology, the Big Fund's chairman, and several senior executives were reported to be engaged in corruption. In 2020, a US$20 billion government-backed startup in Wuhan collapsed without producing a single wafer.[31] Financial incentives, such as those provided by the Big Fund, have mostly attracted the wrong types of firms. In the first 10 months of 2022, more than 58,000 new integrated circuit-related firms were registered. Over 13,000 of these firms moved from their previous operations in unrelated sectors. This practice is known as *zhuanchan* in Chinese. The spokesperson of the National Development and Reform Commission, which is a macroeconomic management agency under the State Council, commented that most firms in the industry had no experience in semiconductors and lack technical know-how and talent.[32]

China has struggled for the past many years to develop its chip industry. High-profile government initiatives to develop the domestic semiconductor industry, such as the Big Fund, have failed to produce much impact on the Chinese semiconductor industry. As we illustrated above, the damages caused by unethical behavior, such as corruption, have been a big impediment to the development of the Chinese semiconductor industry. The achievement level of China's semiconductor industry is nowhere close to the levels of global competitors, such as Taiwan, South Korea, and the United States.

The U.S. government's recent control measures are likely to give a further setback to the Chinese semiconductor industry. The U.S. government has also provided financial incentives for chipmakers under the CHIPS and Science Act to not expand capacity in China for a decade. Overall, the current China–United States chip war presents a further roadblock to the advancement of China's domestic semiconductor industry.

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