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A siege broken? China's processor sector under US sanctions

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Processors are at the heart of the Chinese-US rivalry. They are among the key technologies in which the US holds such global dominance that it can slow China's growth. The unprecedented export restrictions that the US introduced in 2022 were designed to hinder the growth of China's semiconductor sector and prevent this country from manufacturing chips smaller than 14 nm. However, these sanctions have proved to be porous, allowing Chinese companies, which have benefited from extensive state support, to partially develop the production of relatively advanced semiconductor technologies. They have so far failed to achieve the 2–3 nm level that characterises the most advanced chips; they also remain dependent on imports of chip-making equipment. Nonetheless, the ultimate outcome of global competition in this industry will depend not only on the actions of the US and China, but also on the attitudes of other actors involved in international microprocessor supply chains, such as the Netherlands, Japan, Taiwan, and South Korea.

One side effect of the US restrictions on the most advanced semiconductors is that China has ramped up its investment in the production of legacy chips, which are of strategic importance to the defence, automotive, and medical sectors. The outcome of China's efforts in this area will have significant implications for the EU, as China has the potential to become a global powerhouse in this segment by 2026. The need to compete with heavily subsidised Chinese players could derail the EU's plans to revitalise its own semiconductor industry and make European companies dependent on older-generation processors from China.

Since the Chinese telecoms giants ZTE and Huawei were cut off from US technology in 2018, the semiconductor industry has emerged as the primary arena of technological competition between China and the US. At its heart are high-end processors (below 10 nm), which are vital for the development of sensitive technologies such as artificial intelligence (AI). Indeed, the US administration believes that, given China's military-civil fusion, these processors could be used for military purposes: advanced AI models could pave the way for China to develop weapons of mass destruction and state-of-the-art conventional weapons.[1] Therefore, citing national security and the need to check China's military modernisation, the White House has sought to stop China from manufacturing

[1] *Implementation of Additional Export Controls: Certain Advanced Computing Items; Supercomputer and Semiconductor End Use; Updates and Corrections*, The US Department of Commerce, 25 October 2023, public-inspection.federalregister.gov.

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advanced semiconductors and even reverse its capabilities in this area. From Beijing's perspective, the restrictions related to advanced processors also pose a problem for the civilian sector, given their growing importance in the production of high-performance electronics, including high-end laptops, smartphones, and electric cars.[2]

However, the importance of chips in the global economy goes beyond advanced semiconductors. More than 70% of the world's processors are legacy chips (28 nm and higher), which relies on technologies from a decade ago and earlier.[3] They are widely used in the defence industry (including rockets, radars, and drones), vehicles, medical devices, consumer electronics (including lower-end smartphones and tablets) and household appliances.

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The primary tool that the US has employed to halt Chinese expansion in the semiconductor sector is the export restrictions it has imposed on both US entities and any foreign companies that make use of US intellectual property. However, these only apply to advanced chips, not to legacy chips. The US government has described its approach using the phrase 'small yard, high fence'. As part of this policy, it has imposed stringent restrictions on selected advanced technologies with significant military potential while maintaining unimpeded trade in all other technologies.

The US attack and China's response

The 'yard' of US restrictions has been gradually expanding while the 'fence' has been rising higher and higher. Initially, under President Donald Trump, Washington's moves targeted individual Chinese companies on the so-called Entity List, most notably Huawei. The first export restrictions that the US Department of Commerce's Bureau of Industry and Security announced in 2022 were general in nature and only applied to four 'bottlenecks' – the areas where China depends most heavily on the US. These include:

- exports of advanced semiconductors to China,
- sales of the software, hardware, and components that China needs to develop its own production of this technology,
- the blockade of cooperation between US engineers/experts (both US citizens or residents and green card holders) and Chinese entities,
- the requirement that all manufacturers of modern semiconductors (including those outside the US) comply with the new restrictions or face losing access to US semiconductor solutions.

In 2023, the US Department of Commerce decided to step up its pressure on Chinese manufacturers of semiconductors and updated these regulations on 17 October. Aiming to make it more difficult for Chinese companies to acquire restricted processors through third countries, the US expanded the catalogue of processors subject to the restrictions and broadened the regulation's geographic scope to include 43 countries and entities with cloud servers based in countries covered by the US arms embargo. It also restricted the ability of Chinese chip design companies to send their advanced designs to international foundries, such as TSMC.[4]

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[2] Zhao Ziwen, 'EV investors say China will need to catch up in advanced chips to meet future needs of country's booming sector', South China Morning Post, 1 June 2023, scmp.com.

[3] H. Dohmen, J. Feldgoise, 'A Bigger Yard, A Higher Fence: Understanding BIS's Expanded Controls on Advanced Computing Exports', Center for Security and Emerging Technology, 4 December 2023, cset.georgetown.edu.

[4] Foundries specialise in the production of semiconductors designed by other companies under contract.

China has responded to US pressure by continuing its unprecedented and nearly unlimited financial support for the domestic semiconductor industry. The central government plans to allocate $27 billion for the third tranche of its investment fund to develop processors, known as the Big Fund, which was launched a decade ago, while maintaining an elaborate system of local-level subsidies.[5] Even before the US export restrictions came into force, extremely abundant and stable sources of capital had allowed Chinese companies to build up their stockpiles of modern semiconductors, production machines and components. After they had partially lost access to foreign technology, they were able to continue production (despite higher costs and lower productivity) and use various methods to circumvent the US sanctions.

The porous system of restrictions and strategic reserves

The fact that Chinese players continued to climb the technology ladder despite Washington's efforts should be seen as the direct cause of the US tightening its export restrictions in 2023. These advances were enabled in part by loopholes in the US Department of Commerce's regulations, which Chinese companies eagerly exploited. For example, after the restrictions were introduced, iFlytek and SenseTime – two companies specialising in speech and facial recognition technology that the US blacklisted in 2019 due to the Chinese government's use of their products to repress the Uyghur minority in Xinjiang – still had access to high-end semiconductors (including the US-made A100 and H100) and were able to use them to continue their work on ground-breaking AI-based services.

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In order to obtain the processors covered by the US sanctions, Chinese companies have resorted to various practices. They have set up numerous state-supported computer clusters that have been stockpiling chips (such as those made by Nvidia) for years and renting access to this technology to companies placed on the US Entity List. Many operators have been using cloud service providers, as the export restrictions have not directly affected companies such as Amazon and Microsoft. They have also set up shell companies and frequently renamed them to make it difficult to track the final recipients of semiconductors. Smuggling, including practices such as labelling shipments of components as waste parts or attaching extra chips to wafers, has also played a key role. Consequently, even though major Chinese technology companies have been formally unable to purchase advanced processors directly from the US, they have still had partial access to these.

Washington's policy has also diverged from the short-term interests of some US companies. After the export restrictions were introduced, they have modified their processors on several occasions to comply with the US Department of Commerce's sanctions while enabling Chinese operators to continue developing AI. Manufacturers have reduced the overall capacity of their chips but left the performance of these chips in AI applications almost unchanged. For example, Nvidia, which until recently controlled more than 90% of China's $7bn AI chip market, has adjusted its high-end products in this manner on several occasions.[6]

Businesses from China have also retained access to advanced semiconductors due to the stockpiles they built up before the restrictions took effect. These companies were well prepared for intensified technological pressure from the US. The steps that the White House took in October 2022 and in

[5] Dong Cao, Yuan Gao, 'China Readies $27 Billion Chip Fund to Counter Growing US Curbs', Bloomberg, 8 March 2024, bloomberg.com.

[6] S. Nellis, M.A. Cherney, F. Potkin, 'Nvidia plans to release three new chips for China – analysts', Reuters, 10 November 2023, reuters.com.

2023 came as no surprise to China. The imposition of strict export controls on the Chinese telecom giant ZTE and sanctions on Huawei and Fujian Jinhua in 2018, the Dutch government's suspension of foreign sales of extreme ultraviolet (EUV) lithography machines in 2019, and the trade war with the US all made it clear to the Chinese government that the US would seek to cut it off from various technology sectors, most likely starting with the semiconductor industry. At that point, Chinese technology companies began stockpiling advanced processors and lithography equipment to prepare for this challenge. For example, in 2019, Huawei spent around $23.5 billion on chips, components, and materials, which was 73% more than the previous year.[7] In 2020, Chinese companies purchased almost $32 billion worth of lithographic equipment from countries including Japan, South Korea, and Taiwan, up 20% year-on-year.[8] These purchases far exceeded their market needs and were intended as a safety cushion in the event of further US restrictions.

China's Achilles' heel: lithography machines

The capacity to manufacture lithography machines for semiconductors is the weakest part of China's plans to develop its processor sector. In 2023, Shanghai Micro Electronics Equipment announced that it would launch an older-generation (28 nm) chip-making machine, but this has yet to be confirmed.[9] Despite China's pursuit of technological self-sufficiency, it is estimated that less than 5% of the lithographic systems used in Chinese factories have been built in China in recent years.[10]

The coordinated export restrictions imposed by the US, the Netherlands, and Japan were designed to cut off China's access to businesses that account for about 80% of the world's supply of semiconductor manufacturing equipment (in addition to the Dutch-based ASML, these include the US-based Applied Materials, KLA Corp. and Lam Research; the Dutch-based ASM; and the Japan-based Tokyo Electron, Canon, and Nikon). However, Chinese companies have exploited the lack of political will on the part of key US allies, mainly the Netherlands, to implement these restrictions quickly and effectively. The slow progress in this regard has significantly reduced the effectiveness of these regulations.

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The Netherlands banned the sale of lithography machines for manufacturing state-of-the-art processors (EUVs) to China as early as 2019. In March 2023, it also confirmed its intention to join the US sanctions on some older equipment (deep ultraviolet, DUV). However, the relevant legislation did not take effect until September. Subsequently, despite this being in force, ASML continued to obtain export licences for sales of restricted DUVs to China until the end of that year. This approach allowed China to source Dutch-made equipment in quantities that far exceeded its market needs. For example, in September 2023, Chinese imports of lithographic systems from the Netherlands surged by a record 1,850% year-on-year.[11] China also emerged as ASML's second-largest export market, accounting for 26.3% of the company's sales in 2023 and as much as 46% in the record-breaking third quarter.[12] In fact, the company had licences to continue selling some of its DUV machines to its Chinese customers, but these were revoked in early 2024.

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[7] Lauly Li, Cheng Ting-Fang, 'Huawei builds up 2-year reserve of 'most important' US chips', Nikkei Asia, 28 May 2020, asia.nikkei.com.

[8] 'China Stockpiles Chips, Chip-Making Machines to Resist U.S.', Bloomberg, 2 February 2021, bloomberg.com.

[9] 国产"28nm光刻机"又跳票？到底卡在了哪里？ [The launch of China's 28 nm lithography machine to be delayed again? Where did it get stuck?], WeChat, per: picture.iczhiku.com.

[10] Che Pan, F. Bermingham 'China's imports of Dutch chip-making equipment surged tenfold in November after Washington tightened restrictions', South China Morning Post, 22 December 2023, scmp.com.

[11] Data from the General Administration of Customs China, September 2023, stats.customs.gov.cn.

[12] V. Saxena, 'Japan 'Not Planning' to Widen China Chip Curbs Despite US Push', Asia Financial, 10 March 2024, asiafinancial.com.

As a result of pressure from Washington, ASML is also expected to stop servicing some of the DUV equipment it has already sold to Chinese operators.

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The unprecedented US pressure on China's semiconductor sector and the latter's limited ability to develop its own technology and lithography machines have not halted the progress of Chinese companies in producing advanced chips. This was demonstrated by the launch of the Mate 60 Pro smartphone, which features the sophisticated Kirin 9000 processor made by Semiconductor Manufacturing International Corporation (SMIC). It was probably developed through experimentation with less efficient and more expensive techniques than EUV. For example, the process of manufacturing semiconductors using 7 nm technology with a DUV machine involves an estimated yield per wafer of only 15% and requires using the machine three to four times to produce a single chip.[13] This translates into higher costs, heavier use of the lithography equipment, and greater energy consumption, which puts the viability of mass production into question.

On the one hand, access to an almost endless, stable source of capital from state funds means that unlike their Western competitors, Chinese businesses have little regard for cost efficiency. Thus, despite having no access to the most sophisticated machines (EUVs and some DUV models), they can continue to manufacture modern semiconductors in more expensive and less efficient ways. However, on the other hand, the lack of components for foreign-made lithography equipment and the shortage of engineers have already made it difficult for SMIC and Huawei to scale up production. Therefore, faced with a shortage of locally-made AI accelerators, some of China's major technology players such as Alibaba, Baidu, ByteDance, and Tencent have been increasing their orders for Nvidia chips.[14]

Older, but equally important

While China's capabilities in the field of advanced semiconductors remain the subject of heated international debate, another development that deserves urgent attention is the country's rapidly growing potential in the production of legacy chips. Despite their importance to sectors such as defence, automotive, and medical, these chips have not yet been subject to the export restrictions.

Pressure from the US has forced the Chinese government to focus on legacy processors and develop manufacturing capabilities in this niche. Consequently, Chinese companies have been seeking to increase their share in the international market for microcontrollers, analogue processors, and semiconductors used in the automotive industry – older but commonly used technologies where cost efficiency matters more than sophistication.[15]

China currently accounts for 27% of global production capacity for 20–45 nm semiconductors and around 30% for those of 50–180 nm.[16] Its potential stems from robust growth in its foundries: while most legacy processors are designed outside China, local foundries (including SMIC and Hua Hong) have enormous manufacturing capacity. China has also sought to expand this capacity even further for legacy chips. In 2024, it is expected to make one million more processors of this type per month

[13] M. Ahmad, 'The truth about SMIC's 7-nm chip fabrication ordeal', EDN, 23 August 2022, edn.com.

[14] Lin Yiru, 輝達降規版 AI 晶片需求夯 英業達喜迎陸 CSP 廠大單 [Demand for Nvidia's AI chip is on the rise, Inventec is happy to receive a large order from the CSP factory in China], Jingji Ribao, 3 July 2024, money.udn.com.

[15] R. Goujon, J.-P. Kleinhans, L. Gormley, 'Thin Ice: US Pathways to Regulating China-Sourced Legacy Chips', Rhodium Group, 13 May 2024, rhg.com.

[16] J.-P. Kleinhans, R. Goujon, J. Hess, L. Dudley, 'Running on Ice: China's Chipmakers in a Post-October 7 World', Rhodium Group, 4 April 2023, rhg.com.

than in 2023; this means that it is set to manufacture more than the rest of the world combined.[17] China has also announced that it will launch 32 new factories specialising in this technology by 2026, with construction already begun on 22 of these.[18] If all the planned facilities become operational within the next two years, China's share of the global production of 20–40 nm and 50–180 nm semiconductors could reach around 40% to over 50%, respectively over the next three to five years.[19]

> **Pressure from the United States has slowed the growth of China's capability to manufacture advanced semiconductors but has failed to stop it.**

The continued expansion of China's legacy chip capacity raises concerns about the potential risks associated with foreign companies becoming dependent on Chinese suppliers. This dependency could lead to a surge in Chinese semiconductor exports and trigger a price war. We have already seen this scenario unfold in the photovoltaic and electric car industries: massive support from China's state-party apparatus for boosting production capacity in these areas has led, over the long term, to Chinese companies flooding foreign markets with their products and engaging in price dumping. This practice has ultimately put their Western rivals at risk of being displaced and has threatened to make Western economies dependent on Chinese entities. This danger is especially serious as dependence on less advanced processors can affect both the civilian and military sectors.

The long-term consequences of such dependence on legacy chips would be particularly acute for the EU and its automotive industry. For example, China's growing manufacturing capabilities in the field of microcontrollers commonly used in European cars could lead to a strong dependence on Chinese suppliers of this technology. In 2021, the average number of processors in a passenger vehicle was around 1,700; due to the differences in manufacturing processes, major European manufacturers of electric cars (mainly German brands) use significantly more processors than their Chinese counterparts.[20]

Conclusions and prospects

Advanced semiconductors remain at the centre of the technological rivalry between China and the US. Pressure from the United States has slowed the growth of Chinese manufacturing capabilities in this area but has failed to prevent it. However, the effects of these export restrictions should be seen within the next five years. The US Department of Commerce's swift adaptation of its regulations to the changing market situation just one year after they took effect demonstrates the US administration's resolve in halting China's advances in this sphere.

In the current election year, amidst accusations from the Republicans that the existing measures are 'superficial', these efforts may become even more pronounced and result in further tightening of these restrictions. However, any new moves by the US will only be effective if they are coordinated with its strategic allies, such as the Netherlands and Japan, provided that these countries have the necessary political will. The experience of the lithography equipment industry shows that Chinese companies have exploited the Dutch government's slow and inconsistent implementation of these regulations to build up their stockpiles and develop resilience against being cut off from access to Western technology.

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[17] M. Mandavia, 'How China Could Swamp India's Chip Ambitions', The Wall Street Journal, 16 March 2024, wsj.com.

[18] D. Robinson, 'Chip wars could lead to oversupply as China increases domestic capacity', The Register, 17 January 2024, theregister.com.

[19] J.-P. Kleinhans, R. Goujon, J. Hess, L. Dudley, 'Running on Ice…', *op. cit.*

[20] S. Shivakumar, C. Wessner, T. Howell, 'The Strategic Importance of Legacy Chips', Center for Strategic and International Studies, March 2023, csis-website-prod.s3.amazonaws.com.

China has been calling for an industrial policy geared towards developing the domestic semiconductor sector since 2014. Despite its technological advances, China remains heavily dependent on foreign countries for processors. Integrated circuits (ICs) are among China's top imports: in 2023, it imported a total of 479.5 billion ICs worth US$349.4 billion.[21] Therefore, China is still far from achieving the technological self-sufficiency envisioned in the'Made in China 2025'plan announced in 2015. That document set the goal of achieving self-sufficiency at the level of 40% of its total IC consumption by 2020 and 70% by 2025. However, these targets proved unrealistic: in 2021, Chinese manufacturers met only 7% of domestic demand, and fewer than 5% of the lithographic systems used in Chinese factories were produced domestically.[22] One consequence of these efforts to break away from Western technology is that the position of Chinese companies in their domestic market has strengthened.

From the European perspective, the dramatic expansion of China's manufacturing capacity for legacy processors is a key element of its efforts to develop its semiconductor industry. This carries long-term implications for Europe's competitive position and security. Competition with heavily subsidised Chinese players may discourage industry investment on the continent and ultimately make Western companies dependent on older chips imported from China. This is particularly relevant for Intel and TSMC's plans to build new plants in Magdeburg and Dresden, where mature-node processors will be made primarily for the European industry and automotive sector. For this reason, the European Commission will review the extent of European companies' dependence on less advanced processors from China. In the future, the EU may introduce new policies to support the production of such chips in Europe and/or enhance coordination with the US, for example, through the EU-US Trade and Technology Council, to curb imports of legacy semiconductors from China.

[21] Data from the General Administration of Customs China for 2023, stats.customs.gov.cn.

[22] Che Pan, F. Bermingham, 'China's imports of Dutch chip-making equipment…', *op. cit.*