OCTOBER 2023

In Chip Race, China Gives Huawei the Steering Wheel

Huawei's New Smartphone and the Future of Semiconductor Export Controls

By Gregory C. Allen

Introduction

On August 29, Huawei launched its new Mate60 Pro smartphone. Normally, smartphone launches do not attract attention in U.S. national security circles. However, **this one did**, and rightfully so. The Mate60 Pro dramatically marked Huawei's return to the 5G smartphone business after years of ever-tightening U.S. Department of Commerce export controls effectively **cut Huawei off** from 5G technology. How? By restricting Huawei's access to U.S. semiconductor technology, especially chips, chip design software, and chipmaking equipment.

The mobile application processor chip at the heart of the new Huawei phone has an integrated 5G modem. The chip was designed by Huawei's HiSilicon subsidiary and **manufactured** by a Chinese company, Semiconductor Manufacturing International Corporation (SMIC). In March 2023, China's government **reportedly made** Huawei and SMIC, along with two leading Chinese semiconductor equipment companies, Advanced Micro-Fabrication Equipment (AMEC) and Naura, the heart of a new government initiative for semiconductor self-reliance. Huawei is effectively the leader of the Chinese government-backed team, with a privileged position to influence semiconductor policymaking.

SMIC manufactured the new chips at the advanced 7-nanometer (nm) technology node (N+2 in SMIC process naming conventions), **raising questions** in U.S. national security circles about whether the effectiveness of U.S. technology export controls on Huawei—and perhaps China more broadly—is coming to an end.

That was certainly the message that China wanted to send. Chinese state-run media outlets **were exuberant**, arguing in editorials that Huawei's new phone "shows how ineffective Washington's tech sanctions have been" and that "extreme suppression by the US has failed." The new phone was announced during Secretary of Commerce Gina Raimondo's visit to China, which placed a double emphasis on the phone's significance toward U.S. export controls.

However, there is a big difference between claiming that Chinese technological progress proves the current approach to export controls is not achieving all of its desired effects and claiming that Chinese technological progress proves that those same export controls are strategically useless. In principle, either might or might not be true, but the former does not inherently imply the latter.

In the case of the 7 nm chip powering the new Mate60 smartphone, this is a legitimate breakthrough on China's part, not in terms of reaching the global state of the art, but in continuing to make technological progress despite U.S. and allied restrictions. The Trump administration's entity list-based export controls on Huawei and its primary chip manufacturer SMIC had explicitly sought to prevent Huawei and SMIC from designing and manufacturing chips more advanced than 10 nm and from **producing 5G chips**. The same is true of the Biden administration's October 7, 2022, semiconductor export control **policy**, which restricted exports to China of, among other things, advanced semiconductor manufacturing equipment.

While the Huawei phone is not itself a major national security issue for the United States, what the chip inside signals about the state of the Chinese semiconductor industry absolutely is. The 7 nm chips at the heart of the new Huawei phone provide many data points regarding the current and likely future state of the Chinese semiconductor industry. In short, China is still not at the global state of the art for semiconductor manufacturing, but the gap between the peak technological level of China and that of the rest of the world has shrunk, even despite the many hurdles that the U.S. government has attempted to place in SMIC's way.

These advanced chip production capabilities will inevitably be made available to the Chinese military if they have not been already. Thus, the Huawei and SMIC breakthrough raises many tough questions about the efficacy of the current U.S. approach. In fairness to the Biden administration, however, their desired approach—a multilateral one—has only just begun.

This paper will analyze the strategic implications of the Huawei Mate60 Pro and its SMIC 7 nm chip in the context of U.S. and allied export controls on the two companies and on China more generally. It concludes by presenting a list of tough questions where U.S. and allied country policymakers urgently need answers.

Background on the Trump Administration Export Controls on Huawei and SMIC

In Washington, Huawei is mostly known for its telecommunications infrastructure business, but the company was at the forefront of China's remarkable rise in the smartphone, computer, and artificial intelligence (AI) semiconductor chip design industry during the 2010s. In late 2018, there were only two companies in the world selling smartphones with 7 nm mobile application processors, **Apple** and **Huawei**, both of which designed the chips in house and outsourced manufacturing to the Taiwan Semiconductor Manufacturing Company (TSMC).

The **original stated intention** of adding Huawei to the entity list in May 2019 was to punish the company for selling technology to Iran in violation of U.S. sanctions, and **especially for** repeatedly lying to U.S. officials, destroying evidence, and otherwise trying to obstruct justice. The U.S. government also expressed a broader goal of preventing the company from using U.S. technology in ways that contradicted U.S. national security interests. The national security issue was **initially focused** on Huawei's business in 5G telecommunications infrastructure, not smartphones. However, the national security focus grew to include ensuring that Huawei did not use U.S. technology to assist it in evading the reach of U.S. export controls, which thereafter led to a more generalized focus on Huawei's activities related to chip design and chip manufacturing, including for base stations and smartphones.

As described in a previous **CSIS paper**, the 2019 U.S. export controls on Huawei—as well as the earlier April 2018 export controls on Chinese telecom firm ZTE—were a landmark in the Chinese national security policy community. China's pursuit of semiconductor self-sufficiency had already been a top Chinese industrial policy priority from the **Made in China 2025** policy of 2015 and even earlier with China's establishment of its "Big Fund" in 2014. However, after 2018, semiconductor self-sufficiency became a top Chinese **national security priority**, **not just** an industrial policy one. Semiconductor self-sufficiency received more than $100 billion in Chinese **government financial support** and regularly attracted the **personal attention** of Chinese Communist Party general secretary Xi Jinping.

De-Americanization of the supply chain became a priority not just for Huawei and the Chinese government, but also for many leading Chinese chipmakers. For example, in May 2021, **Nikkei Asia reported** that Yangtze Memory Technologies Corporation (YMTC), one of China's most advanced semiconductor manufacturers, had already been engaged in a full-blown de-Americanization campaign involving the full-time work of more than 800 staff for two years. This included the establishment of multiple major partnerships with domestic Chinese equipment producers. Industry sources told CSIS that YMTC also conducted a close examination of the foreign sources within the supply chain of U.S. equipment manufacturers and launched an effort to begin direct purchases from the foreign suppliers of U.S. firms.

In May 2020, the Department of Commerce **concluded** that the 2019 Huawei entity listing had an effect but failed to achieve its goals: U.S. chip manufacturers such as Intel, Qualcomm, and Xilinx **continued selling** many types of advanced chips directly to Huawei, as many of their chips were not produced in the United States and therefore were not subject to the export controls as written at the time. More importantly, however, Huawei was successfully designing replacement chips (using U.S. chip design software) and contracting with chip foundries outside of China to manufacture them (in facilities that relied heavily on U.S. chip manufacturing equipment). Industry sources told CSIS that U.S. companies were losing revenue not as a direct result of no longer selling to Huawei, but rather because Huawei was replacing U.S. chips with their own self-designed versions.

Then secretary of commerce Wilbur Ross put it **this way**: "Despite the Entity List actions the Department took last year, Huawei and its foreign affiliates have stepped-up efforts to undermine these national security-based restrictions through an indigenization effort. However, that effort is still dependent on U.S. technologies."

The May 2020 updated export controls therefore applied a **revised version** of the Foreign Direct Product Rule (FDPR) to prevent foreign entities from assisting Huawei and its chip design subsidiary HiSilicon in designing or manufacturing chips that were a "direct product" of U.S. technology. Overnight, Huawei's access to semiconductors shrank drastically to only three sources: the less technologically advanced subset of chips for which U.S. licenses were **still being approved**, the vast set of U.S. and foreign chips that were manufactured or assembled outside of the United States and were therefore not subject to the U.S. rules, and **the enormous stockpile** of critical chips that Huawei **had amassed** by making purchases when they were still legal. The Chinese chip manufacturers that were still willing to work with Huawei generally had dramatically inferior technology. Even the initial application of the FDPR in May 2020 did not affect chips produced outside of the United States, with the exception of those designed by HiSilicon. This allowed Huawei to engage in a **massive stockpiling effort**.

Then, the Trump administration decided to finally cut off Huawei's access to chips and **updated** the FDPR in August of 2020 to apply not only to Huawei and HiSilicon's own chips but to all chips produced using U.S. technology that was being sold to Huawei.

Despite Huawei's stockpiling, the **May and August 2020** controls eventually did serious damage. Huawei's worldwide revenue **declined 28.5 percent** between 2020 and 2021. The damage was especially severe in Huawei's smartphones business, which required a much higher volume of advanced chips and was essentially cut off from 5G technology. Early in 2023, Huawei **told its investors** that it optimistically hoped to sell a mere 30 million phones that year, an 88 percent decline from the 240 million it sold in 2019. Huawei had to take dramatic steps, such as selling off the majority of its consumer smartphone business to a new spinoff known as Honor, as well as its Intel-based X86 server business, which is now known as "XFusion." These moves allowed Huawei to conserve its massive chip stockpile for more strategic parts of its business such as network infrastructure and premium smartphone products.

The Mate60 Pro marks Huawei's return to the 5G smartphone business and thereby proves that the effects of the Trump-era controls are rapidly coming to an end as Huawei redesigns its supply chain to rely more on its HiSilicon subsidiary for chip design and more on SMIC (as opposed to TSMC of Taiwan) for manufacturing. Huawei's **revised sales projections** for 2023 suggest that it expects to sell roughly 40 million smartphones in 2023, of which roughly half will use the new 7 nm chips. Industry analysts with ties to Huawei's supply chain report that Huawei expects to sell **60 million** smartphones in 2024, of which **most or all** will use Huawei-designed, SMIC-manufactured mobile application processors with integrated 5G modems. The Mate60 Pro's memory chips **are manufactured** by SK Hynix of South Korea. SK Hynix has **stated** that it stopped doing business with Huawei after the introduction of U.S. sanctions and that it is investigating how Huawei came to use its chips. Though selling 60 million smartphones would still be a significant decrease from Huawei's 2019 peak, it likely signals the start of a comeback for the company.

The sophistication of the Huawei chip from a design perspective—it is **at least equal to and often better than** the best Western-designed smartphone chips of the 7 nm era—indicates that there has been no significant erosion in HiSilicon's design excellence. Moreover, Huawei's integration of the 5G modem onto the same silicon die as the mobile application processor brings many **technological performance benefits**. Huawei has achieved this three years before Apple currently expects to do so.

Radio-frequency engineering, the critical technology involved in developing modems, is the technical core of Huawei's business, and industry sources told CSIS that Huawei is far ahead of most companies in this space.

While this supply chain is still critically dependent upon U.S. technology, some of the pre-October 2022 export controls and entity list restrictions on Huawei's suppliers were not especially well designed for a goal of blocking SMIC from producing 7 nm chips, despite that being their explicit goal. For example, the entity list license review policy for SMIC established in December 2020 states that license applications to export to **SMIC will be reviewed** under a policy of "presumption of denial for items uniquely required for production of semiconductors at advanced technology nodes (10 nanometers and below, including extreme ultraviolet technology); Case by case for all other items."

The problem with this standard is the "uniquely required" phrase. This is both vague and a poor fit for the reality of semiconductor manufacturing. Nearly all semiconductor manufacturing equipment that can be used to produce 10 nm and below chips can also be used to produce less advanced 14 nm and above chips and vice versa. This is known as "capex recycling" by the semiconductor industry, and industry sources told CSIS that equipment reuse rates between these nodes are sometimes higher than 90 percent. Furthermore, the rules only applied to "U.S. origin items and technology" which did not include a major portion of semiconductor capital equipment produced by U.S. firms outside of the United States in locations such as Singapore and Malaysia. In some cases, the companies did not even need to apply for a license, as their equipment was not technically U.S. origin and was therefore not even subject to the rules.

The companies applying for export licenses simply stated this truth in their export license applications, at which point the Department of Commerce frequently approved them. Department of Commerce license application reviewers are (understandably) trained to follow the letter of the law, even if that law's text is a poor fit for what department leadership describes as the goal of that law. According to a **Reuters analysis** of Department of Commerce documents, "113 export licenses worth $61 billion were approved for suppliers to ship products to Huawei (HWT.UL) while another 188 licenses valued at nearly $42 billion were greenlighted for Semiconductor Manufacturing International Corp (SMIC) (0.981.HK)" between November 2020 and April 2021. However, industry sources told CSIS that nearly all applications for export licenses to SMIC's most advanced facilities were typically denied after August 2021.

Thus, almost the only types of sales that the December 2020 SMIC entity listing definitively blocked were for the technology that it specifically stated would be prohibited, namely extreme ultraviolet (EUV) lithography equipment, which United States companies do not principally supply. Thus, blocking EUV sales required a policy change by the Dutch government since the sole supplier of complete EUV lithography machines is a Dutch company, ASML. The Trump administration reportedly reached an informal agreement with the Dutch government in **early 2020**. According to a later published **Dutch government document**, the Dutch Ministry of Defence was a strong supporter of limiting EUV exports to China at the time.

Industry sources told CSIS that, at the time, ASML was poised to ship EUV tools to China and that SMIC was planning to work with key research labs in Europe such as the Interuniversity Microelectronics Centre (IMEC) to help develop their EUV-based manufacturing process.

Blocking China from acquiring EUV technology has complicated China's path to producing chips at technology nodes more advanced than 7 nm. However, it actually did not block SMIC from legally acquiring all the equipment required to manufacture 7 nm chips, since much of the advanced deposition, etching, inspection, and metrology equipment was not blocked from purchase. Moreover, advanced deep ultraviolet (DUV) lithography equipment can be used as an alternative to EUV for the production of 7 nm chips.

The clearest proof of this is the fact that SMIC was **already producing** and selling 7 nm chips no later than July 2022 and potentially **as early as July 2021**, despite having no EUV machines. TSMC, the Taiwanese semiconductor manufacturing giant, achieved 7 nm mass production by 2018 **without using EUV technology**. Adopting EUV, however, brings benefits in production reliability, speed, scale, and therefore economic competitiveness.

SMIC's initial 7 nm chips (**using SMIC's N+1 process**) were specialized chips for cryptocurrency mining. Such chips are less complicated to manufacture than a smartphone's application processor due to their lack of dense static random-access (SRAM) memory. For SMIC, the barrier to making more complex 7 nm chips in 2021 was a need for improved operational experience and skill in using the equipment it already had to improve its 7 nm production process and then reliably operate it at scale, not necessarily a need for additional equipment.

The Huawei chip (**using SMIC's N+2 process**) proves that SMIC's skill in manufacturing at the 7nm node has advanced significantly since July 2022, despite the Biden administration's new semiconductor export control architecture that was launched on **October 7, 2022**. It is worth noting, however, that SMIC's work on N+2 has been underway at least since **early 2020**. Thus, much of the relevant development work took place long before October 7. Industry sources told CSIS that, both before and after October 7, SMIC was the beneficiary of significant foreign technical advice, though after October 7, this advice was limited to non-U.S. persons.

Huawei Mate60 Pro and SMIC 7 nm Chip Implications for Biden-Era Export Controls

The Biden administration's **October 7 export controls** doubled down on the Trump administration's attempt to restrict the export of U.S. advanced semiconductor manufacturing equipment to China. However, the Biden administration went significantly further in an effort to not only restrict the pace of China's technological progress but also to, as much as possible, **actively degrade** the current state of the art back to a **pre-14 nm** manufacturing level.

The policy also went beyond mere entity listings and put blanket restrictions on all of China that sought to, in some instances, cut off SMIC and other advanced Chinese chipmakers from the supply of U.S. equipment, spare parts, software updates, components, maintenance, and even expert advisory services. The goal was to force existing Chinese chip manufacturers to shut down or reconfigure their advanced product lines to focus on legacy technologies. SMIC is the most advanced logic chip foundry in China, so it was absolutely a target of this policy.

Technology degrading did indeed happen in the case of YMTC, which was forced to **abandon**—perhaps only temporarily—plans for a 232-layer NAND flash memory product. However, the Huawei Mate60 Pro demonstrates that SMIC's peak manufacturing technological capability has not only not been degraded, but it has advanced.

For the Biden administration, the Mate60 Pro launch is an important data point that raises legitimate questions regarding the key assumptions underlying their signature semiconductor export control policy. Most obviously, this development suggests that the October 7 export control policy, and especially the recently updated export control policies of the Japanese and Dutch governments, were needed earlier to have a realistic opportunity to achieve all their intended effects. However, it also shows one of the key mechanisms of the policy—end-use restrictions on advanced semiconductor manufacturing equipment—is not working as intended and will require an update to close existing loopholes.

Industry experts consistently told CSIS that no combination of Chinese semiconductor manufacturing equipment companies can produce even 10 percent of the diverse types of advanced equipment required to operate a 7 nm chip foundry. In fact, there is no 7 nm fab in the world that does not rely upon controlled U.S. technology, so it is quite clear that SMIC is using U.S. technology—machines, components, spare parts, and materials—in producing these chips for Huawei.

It is also highly likely that Huawei designed these chips using software tools from U.S. electronic design automation (EDA) companies. Huawei only **announced** in March 2023 that it had finally made a breakthrough on 14 nm software tools after years of work. These claims have yet to be verified externally. The idea that Huawei had completed development of its more advanced 7 nm EDA tools in time to design the core processors for a phone that launched in September is **not consistent** with typical industry chip design or EDA tool development timelines.

The companies that do have mature EDA software available for designing 7 nm chips are all American. Prior to Huawei's entity listing, Huawei was legally allowed to license this software from the companies and did so. That was how Huawei designed its first 7 nm chip **back in 2018**. However, the U.S. providers of EDA software have been prohibited from renewing Huawei's software licenses or providing software updates since 2020. Industry officials told CSIS that the Huawei chip was most likely designed with a pirated version of U.S. EDA tools. Chinese software piracy is a **well-known problem** in the EDA industry.

Thus, the fact that Huawei and SMIC used U.S. technology is not controversial. It is clearly the case. Determining whether Huawei and SMIC's use of U.S. technology involved violations of U.S. law—either by those companies, by their Chinese suppliers, or by the U.S. companies that produce the technology—is not quite as obvious. However, there are many suspicious circumstances that deserve immediate inquiry. The following sections of this paper will detail the regulatory mechanisms by which the October 7 export controls were intended to address the gaps in the Trump administration policy and also assess the questions that U.S. policymakers should be asking as they consider updated controls.

Analysis of Existing U.S. Regulatory Mechanisms to Prevent 7 nm Chip Fabrication

The Trump administration took three major actions in the semiconductor sector. First, it placed entity list restrictions on hundreds of Chinese companies, including ZTE (later **removed**), **Fujian Jinhua**, Huawei, and SMIC. Second, the Trump administration **adjusted the scope** and application of the

FDPR. Third, it **persuaded** the Dutch government to restrict sales of EUV machines to China as a whole based on an informal agreement to deny a license for technology that was already controlled on a multilateral basis through the Wassenaar Arrangement control list.

The Biden administration did not reverse or weaken any Trump-era semiconductor trade restrictions and added to them significantly by adopting new restrictions that applied to China as a whole. Most importantly, the Biden administration's October 7, 2022, policy was focused on restricting China's access to **advanced chips for AI development**, but that policy significantly expanded export regulations related to semiconductor manufacturing equipment in order to prevent China from domestically producing alternatives to the advanced AI chips that the United States no longer allowed exporting.

The policy's **chip equipment restrictions** were split into three broad categories:

- **Blanket prohibition of exports of a narrow set of advanced deposition equipment to all of China, as well as all parts and accessories related to that equipment:** These restrictions took the form of creating a new Export Control Classification Number (ECCN) 3B090, which was restricted under a Regional Security ("RS-China") justification.

- **End-use prohibition of exports intended for use in advanced node semiconductor manufacturing or where the manufacturing node is not clear:** The second major restriction was the creation of a new license restriction based on end use with a presumption of denial, by adding section 744.23 to the Export Administration Regulations (EAR). This effectively imposed a blanket ban on exports to China in cases where the exporter in question **has "knowledge"** that the exported goods will be used for a restricted end use. The restricted end uses in question are production of advanced node semiconductors—defined as logic chips at or below 16 nm, DRAM memory chips at or below 18 nm, and NAND storage at or above 128 layers—or supporting Chinese production of any semiconductor manufacturing equipment, components, or parts. An additional near-blanket prohibition exists for selling to any facility in which the seller knows that the facility produces chips but does not know whether or not the chips produced at that facility are at an advanced technology node.

  To ensure that shipments of U.S. technology for restricted goods (or even transfers of relevant subject matter expertise) would not occur through foreign subsidiaries, joint ventures, or partnerships, the regulations modified section 744.6 of the EAR, the so-called "U.S. persons rule," which dramatically expanded licensing requirements. It also applies an updated FDPR provision, section 742.6(a)(6), to prevent foreign firms from using U.S. technology to assist China in pursuing the end uses specified in section 744.23. These restrictions apply on a China-wide basis, though only for restricted end uses and end users.

  The broader set of equipment and components restricted by section 744.23 includes all items subject to the EAR, of which ECCNs 3B001, 3B002, 3B090, 3B611, 3B991, and 3B992 directly pertain to semiconductor manufacturing equipment and components. This equipment is still generally allowed to be sold to China in cases where two criteria are met. First, the exporter must not have specific knowledge that the buyer intends to use the equipment for advanced node manufacturing. Second, the equipment must not be destined for end use at a facility in which the equipment provider does not know whether or not it is engaged in advanced node manufacturing.

For the newly restricted types of chip equipment covered under 3B991 and 3B992, the exporter does not even have to apply for a license to export the goods to China in cases where the exporter has no specific knowledge that they are going toward a prohibited end use or end user.

- **Blanket export ban to YMTC, China's most advanced NAND company:** Two months later, in December 2022, the U.S. government also **added YMTC** to the entity list under a blanket presumption of denial for exporting "all items subject to the EAR." Any purchase of semiconductor manufacturing equipment or components by YMTC after December 2022 would have been in some way illegal under U.S. law, unless the U.S. government had approved a license.

The Biden administration adopted these new rules in an attempt to degrade the peak technology level of the Chinese chipmaking sector through the loss of access to spare parts, maintenance, and advisory services. It would, for example, be illegal for any U.S. company to provide SMIC with spare parts or new equipment if the U.S. company had knowledge that SMIC was using the equipment to support its 7 nm manufacturing line. In practice, this means that all shipments to SMIC's SN1 and SN2 fab facilities in Shanghai are prohibited. For shipments to other SMIC facilities, the **October 7 policy** instructs companies to follow official "Know Your Customer" **guidance** and best practices, including obtaining a signed end-use statement from the customer and also evaluating "all other available information to determine whether a license is required pursuant to § [section] 744.23."

Overall, this is a significantly stricter due diligence requirement than is typical for Department of Commerce export controls, but it still raises the question of just how much leverage the U.S. government will have to punish companies that use already-installed equipment for prohibited end uses. It also raises the question of whether SMIC and other Chinese firms could be deceiving U.S. firms about the true end uses of their purchases.

Why Did the October 7 Export Controls Fail to Prevent SMIC from Advancing 7nm Production?

It is clear at this point that the October 7 policy has thus far failed to degrade SMIC's peak technological capability, but that is not especially surprising. SMIC had already begun a ferocious capacity-expansion and equipment-buying campaign both **before and after** its December 2020 entity listing. As noted above, the U.S. restrictions prior to October 7 did very little to limit SMIC's purchase of advanced semiconductor manufacturing equipment, even when that equipment was known to be directly supporting a 7 nm production line. SMIC had 14 nm fin-shaped field-effect transistor (FinFet) production commercially available in 2019 and thus had nearly all the equipment it needed to advance to 7 nm due to the ability to "recycle" the equipment for future nodes.

In much the same way that Huawei had stockpiled a two-year supply of chips prior to U.S. entity restrictions taking effect, SMIC has amassed a large number of machines and potentially also a large stockpile of spare parts that it can draw from. In recent years, Chinese semiconductor manufacturing equipment purchases have been so extensive that non-Chinese chip manufacturers have been complaining that it is **delaying equipment providers** from completing their non-Chinese orders on time. Industry sources told CSIS that equipment providers routinely refer to Chinese customers under the label of "non-market demand," meaning that the customers were buying for strategic reasons unrelated to market conditions or profit maximization.

Moreover, industry sources told CSIS that, prior to the October 7 regulations, some semiconductor manufacturing equipment, components, and spare parts from U.S. companies were exported to China without a license via foreign-headquartered partners. In the absence of the application of the FDPR or the U.S. persons rule, this is not necessarily a violation of U.S. law. Industry sources also told CSIS that SMIC has set up a network of shell companies and partner firms in China through which it has been able to continue acquiring U.S. equipment and components by deceiving U.S. exporters. If true, sales to such shell companies would involve violations of U.S. law by SMIC, though not necessarily by U.S. companies, so long as the U.S. firm had no knowledge of the fact that the shell company was acting on behalf of SMIC.

In cases where SMIC did face a legitimate problem due to U.S. restrictions, it was, until very recently, largely unrestricted in its ability to purchase equipment and spare parts from the Netherlands, Japan, South Korea, and Taiwan. According to a ***Financial Times* analysis** of Chinese customs data, the total value of Chinese imports of semiconductor manufacturing equipment increased from $2.9 billion over the two months in June and July 2022 to $5.0 billion over the same two months in 2023. The analysis further found that "most of the imports came from the Netherlands and Japan." **Japan's export controls** only took effect in late July 2023. **The Netherlands' export controls** only took effect in September, and Dutch companies are being **allowed to complete** the delivery of previously approved licensed exports to China even if those deliveries occur after September 2023, so long as the shipment is completed by January 1, 2024.

The Chinese customs data analyzed by the *Financial Times* includes finished and fully integrated manufacturing equipment but does not include components, spare parts, and materials. One industry source told CSIS that, because of this omission, the customs data significantly understates the extent to which U.S. technology is being displaced by foreign suppliers. This individual said that as U.S. equipment firms have been forced to reduce their presence in the market, "Japanese firms have been gorging themselves on Chinese revenue from selling fully integrated machines. Korean firms have been gorging themselves on selling subsystems and spare parts." In conversations with CSIS, multiple industry sources highlighted the problem of South Korean firms backfilling export-controlled U.S. technology and also training Chinese staff in both equipment maintenance and fab operations.

In early 2021, SMIC **told its Chinese government investors** that its goal for the SN1 chip fab—SMIC's second most advanced facility and the one which produces 14 nm node wafers—was production capacity of 35,000 finished wafers per month (WPM).

SMIC's most advanced chip fab is SN2, which is part of the same **SMIC Southern Shanghai campus** as SN1. SN2 is the facility where SMIC conducts advanced node research and development (R&D) and is also the facility where SMIC has begun mass production of its 7 nm (N+1 and N+2) processes. According to a **June 2020 report** by Guolian Securities, a Chinese investment advisory firm, SMIC planned for 7 nm production capacity at SN2 to also reach 35,000 WPM on an unspecified timeframe. According to one Chinese semiconductor industry analyst, SMIC also **planned** as recently as September 2022 to eventually pursue 5 nm production at SN2 despite lacking access to EUV machines. For comparison, TSMC first achieved 7 nm mass production without EUV but later upgraded its 7nm process to use EUV. No major international chipmaker has ever engaged in mass production of 5nm chips without using EUV lithography machines.

Both the SN1 and SN2 projects **were announced** in 2017. The SN1 facility was producing 3,000 WPM in late 2019, **6,000 WPM** at the 14 nm node in June 2020, and in February 2021 **SMIC claimed** that SN1 had achieved **15,000 WPM** production capacity by the end of 2020. According to a SMIC press release in early 2020, SMIC had originally anticipated hitting the 35,000 WPM production target for SN1 by the end of 2022. More likely than not, SMIC has by now hit this SN1 production capacity target. SMIC **stated** in February 2023 that it would accelerate capacity expansion despite weakening demand and market oversupply. DigiTimes Asia **reported** in June 2023 that SMIC was continuing to offer and deliver 14 nm production to customers.

One industry source told CSIS that SMIC's FinFET production capacity across both SN1 and SN2 is currently 35,000 WPM and that roughly one-third of this capacity is currently being devoted to 7 nm production.

No data is publicly available on SN2's progress in production capacity ramp up. T.P. Huang, an independent semiconductor industry analyst, **estimates** that by the end of 2023, SMIC will have legally acquired **enough** advanced DUV lithography machines across all SMIC facilities to eventually support production of more than 50,000 FinFET WPM, which would have to be **split across** the 14 nm and 7 nm production. It is unclear what share of these machines currently resides at SN1 and SN2. Based on analysis of a SMIC notice, Huang **projects** that all SN2 equipment installations will be completed by July 2024.

Industry sources told CSIS that this estimate is reasonable and that SMIC will likely reach production capacity of 50,000 WPM across SN1 and SN2 by the end of 2024. SMIC has existing customers for its 14 nm capacity, so presumably it will not immediately reallocate all of its machines to 7 nm. In lithography, the **Dutch export controls** only restrict exports of EUV machines and the most advanced DUV machines, so it is possible that additional future purchases could increase SMIC's potential 7 nm production even beyond 50,000 WPM.

For most new semiconductor manufacturers, manufacturing **yield** (the share of the chips on the finished wafer that are usable) starts at a low level and then improves as the company's mastery of a new technology node and production process improves. Industry sources told CSIS that SMIC's current yield is roughly 50 percent. By comparison, TSMC's early production with 7 nm was already achieving **76 percent yield** in 2017, even before introducing EUV technology. It is reasonable to assume that SMIC's yield will improve over time, as more of ASML's most advanced DUV lithography machines are delivered and as SMIC gains operational experience with the N+2 process node. However, SMIC may never match the high yields that TSMC achieved after introducing EUV.

The yield rate directly relates to the economics of chip production. Costs are incurred on a per-wafer basis, so increasing the number of usable chips per wafer is equivalent to increasing output without increasing costs. Per chip costs are not typically made publicly available, but Fomalhaut Techno Solutions, a Tokyo-based research company, **estimated** in 2022 that Apple paid TSMC $110 per chip for its 4 nm production, up from $46 per chip for TSMC's 5 nm production. TSMC's 5 nm production process, which used EUV, reportedly achieved **excellent yields** early in its history.

If SMIC hypothetically had 100 percent yield and 35,000 7 nm WPM production capacity at SN2 with 550 Huawei chips per wafer, then SMIC could produce enough chips for 231 million phones over the course of a year. As mentioned previously, Huawei only expects to sell 60 million such phones in 2024.

This is no doubt exactly what Huawei hopes for: to win back the customers it **lost to Apple** and other competitors during the years it was cut off from 5G chips. The Chinese government's instructions to all employees of the Chinese government and all state-owned enterprises **not to use Apple phones** might soon be followed by nationalist pressure to buy Huawei's alternative, even if the technical performance is inferior. If SMIC's yield remains low, Huawei's 5G smartphone business may require significant subsidization or a protected domestic market to be economically viable. Assuming that Huawei is paying SMIC's per wafer prices comparable to what Apple paid TSMC for 7 nm capacity—$10,000 per wafer—then $4.2 billion in annual subsidies would be enough to pay for Huawei buying the entirety of SMIC's annual 7 nm production assuming 35,000 WPM.

Smartphone companies tend to be early adopters of new semiconductor technology nodes. If the production capacity was directed not toward phones but other uses, such as manufacturing AI chips, which tend to be far larger, then SMIC could manufacture perhaps **10 million per year** even at low yields. AI chips tend to be much larger and thus put more of their production investment at risk from manufacturing defects. AI chip producers tend to adopt a manufacturing process node roughly two years after the smartphone early adopters because by that time the defect rate has come down considerably. Further analysis of the implications of this chip for China's AI sector is included later in this report.

It is currently unclear based on the available information whether or not SMIC has also benefitted from illegal technology purchases made in violation of the October 7 or other U.S. export controls. Dylan Patel, Afzal Ahmad, and Myron Xie of the semiconductor consulting firm Semianalysis have **argued forcefully**, however, that this is indeed the case. Their provocative claims are worth quoting at length:

> The equipment companies such as Applied Materials, Lam Research, Tokyo Electron, KLA, Screen, ASM International, Kokusai, etc. are selling basically every tool they offer to China. This is because most deposition, etch, metrology, cleaning, coaters, developers, ion implant, epitaxy, etc. tools for 7nm and even 5nm can also plausibly be used in 28nm. These tools are being sold to SMIC for "28nm," but, in reality, SMIC is lying to the firms' faces and using them for 7nm.
>
> While SMIC is expanding 28nm and other trailing edge nodes, it is much less than they claim as these tools are being rerouted to leading edge. It's even possible that people within these equipment firms know what's happening, but are turning a blind eye.

The Semianalysis authors did not specifically disclose the sources for these claims in their article but elsewhere cited "rumors from China." One industry source told CSIS that illegal diversion of U.S. exports in materials and spare parts to prohibited Chinese end uses and end users was "rampant" even after October 7, 2022, and that the end-use controls outlined in section 744.23 were being intentionally violated by SMIC and other advanced Chinese chip manufacturers. Other industry sources told CSIS that rumors of diversion at the fully integrated equipment level were entirely false and that diversion at the subsystem and part levels was done by third parties, not U.S. firms. These accusations may or may not be true, and there has been no proof provided to verify or disprove the accusations. Nevertheless, they deserve immediate investigation by the U.S. government.

If exports are being diverted from their legally licensed destination toward fabs that are operating toward prohibited end uses, that is strong legal justification for the U.S. government and its allies to strengthen export control restrictions. It is at a minimum plausible that SMIC's claims to be expanding capacity at 28 nm are disingenuous. Other Chinese chipmaking companies have built fabs with the **explicit intention** of starting production at 28 nm and later shifting production to more advanced technology nodes. In February 2021, a Chinese news outlet **reported** that SMIC's Huahong Factory No. 6 in Shanghai would begin production at 28 nm but that SMIC ultimately planned to upgrade the facility to 14 nm with a production capacity of 40,000 WPM. However, SMIC does have a large and growing set of customers for 28nm production, so this transition to 7nm, even if planned, may be well in the future.

Impacts of Export Controls on China's Chipmaking and Chip Equipment Industries

However, even if there are legal grounds for expanded export controls, the U.S. government must have a clear sense of what effect strengthened export controls are realistically going to have and how the United States would know whether or not its efforts are succeeding.

YMTC is the clearest test case for the power of unilateral U.S. semiconductor export controls against Chinese chipmakers. With a blanket export ban adopted in December 2022, YMTC's entity list restrictions are far stronger than anything that the United States placed on SMIC or included in the October 7 regulations. Reporting by the ***Financial Times*** and ***South China Morning Post*** claims that YMTC was initially hit hard by the controls, but that a combination of government subsidies, Dutch and Japanese equipment, previously purchased U.S. equipment, and the improving quality of Chinese equipment suppliers has given YMTC the confidence to restart advanced NAND memory production and make major investments.

It is worth emphasizing again that YMTC had been **extensively preparing** for U.S. export controls since 2019—three-and-a-half years before the time they arrived. Furthermore, YMTC will have arguably had more than four-and-a-half years of preparation by the time Dutch controls take full effect in January 2024.

At the same time, China's domestic semiconductor equipment sector is experiencing significant growth and **collectively organizing itself** around the goal of producing alternatives to U.S. equipment, components, and spare parts. **Analysis** by CINNO Research, a Chinese consultancy, finds that the 10 largest Chinese semiconductor manufacturing equipment firms have seen their revenue increase 39 percent compared with 2022, totaling $2.2 billion for the first half of 2023. This builds on progress that was already underway even before October 2022. Dr. Doug Fuller of the Copenhagen Business School **claims** that Chinese semiconductor equipment firms have increased their share of China's domestic market from 8.5 percent in 2020 to 25 percent in the first 10 months of 2022, though these sales were overwhelmingly concentrated at legacy nodes and far from the state of the art. Chinese equipment firms are also concentrated in non-critical processes.

Moreover, after October 7, the Chinese government has further increased its already massive subsidization of the semiconductor industry. In September, Reuters reported that China is preparing to launch a new **$40 billion state-backed investment fund** for its semiconductor sector. This follows similarly massive funds launched in 2014 and 2019. On September 18, 2023, the Chinese government strengthened R&D **tax incentives** such that 120 percent of the cost of all R&D by Chinese semiconductor companies can now be deducted from taxes. The semiconductor industry is among the most R&D-intensive industries worldwide, so this is a massive subsidy stacked on top of many other massive subsidies that remain in effect.

The Dutch and Japanese export controls are a license requirement with unclear (at least in terms of publicly available information) license approval criteria. It is possible that the Dutch and Japanese licensing restrictions will be enforced similarly to the U.S. framework, which applies extremely broad restrictions for the advanced fabs such as the one that YMTC is building. If that is indeed the case, YMTC will be cut off from nearly every foreign machine that it needs to build and maintain its advanced fab legally. Whether or not illegal means are available will depend upon the strength of enforcement capacity.

However, it is worth asking whether or not Dutch or Japanese export controls can be truly effective in the absence of Dutch and Japanese legal equivalents to the U.S. FDPR and U.S. persons rule. The absence of such provisions has been a challenge for earlier Japanese export controls. Most notably, a recent **World Bank analysis** of Japan's 2019 export controls on the sale of semiconductor manufacturing chemicals to South Korea found that Japanese chemical suppliers responded by simply shifting some production of the chemicals from Japan to their subsidiary companies headquartered in South Korea or by forming joint ventures with South Korean firms.

This was not in legal violation of Japanese export controls, though it was obviously in violation of the policy's intent. If sales and shipments of Dutch and Japanese equipment, components, and spare parts are simply routed through foreign subsidiaries or distributors, then the export controls will have limited effect on China's ability to expand advanced node production. Many Dutch and Japanese business executives will likely use all legal means available to continue sales to China. At least one Japanese business executive has already **stated his intention** to "develop duplicate supply chains—one for the U.S.-led economic bloc and one for [the] China-led bloc."

One industry source told CSIS that "we're definitely seeing the Chinese equipment industry making progress faster than previously expected." The degree of dominance of U.S. firms in certain categories of semiconductor manufacturing equipment at the fully integrated systems level is real, but that is as the manager of a **global supply chain** in which other countries provide many components and subsystems that make up important parts of the finished system.

Industry sources told CSIS that Chinese semiconductor equipment companies have worked aggressively to map U.S. equipment firms' supply chains and to develop independent purchasing relationships with U.S. equipment companies' non-U.S. suppliers. Because Chinese semiconductor equipment and component firms have already been subject to blanket U.S. export controls and have weak prospects for sales outside of China, they have little incentive to respect U.S. intellectual property, export controls, or other laws. Thus, these firms take advantage of non-U.S. suppliers where they are can and seek to reverse engineer U.S. or allied technology where they must.

One Chinese equipment company, AMEC, **claimed** at an August 2023 investor relations meeting that they have 35 different types of etching equipment tools under development that are designed to provide full coverage of the etching processes required for manufacturing sub-20 nm DRAM memory. Of these 35, AMEC claims that 14 of the tools are already in mass production, while the other 21 have completed laboratory verification. An industry source told CSIS that AMEC's tools that have completed laboratory verification are two to five years away from being viable for mass production under ideal conditions, and that the actual time to availability may be longer. Regardless, this still represents significant progress from where AMEC was three years ago. As mentioned above, AMEC is part of the China's new approach of **centralizing collaboration** between the Chinese government and leading private sector semiconductor firms, a collaboration led by Huawei.

Industry sources also told CSIS that South Korean, European, and Japanese subsystems suppliers are aggressively pursuing the Chinese market that has been opened up in the wake of U.S. export controls. Two sources specifically stated that South Korean firms have been instrumental in providing spare parts, maintenance, and advisory services related to U.S. equipment.

YMTC likewise has little incentive to comply with U.S. laws. As long as sales of components and materials are continuing through distributors in China, genuinely cutting YMTC off will be difficult unless the United States and its allies are willing to tighten restrictions on a China-wide basis. One industry expert told CSIS that the Department of Commerce has failed to effectively identify all the shell companies and industry partners that YMTC uses to continue receiving U.S. technology in violation of export controls. Multiple industry sources said the same was true of SMIC.

CMXT, a Chinese DRAM memory producer, is **reportedly** spending hundreds of millions of dollars to purchase legacy equipment suitable for producing large quantities of legacy DRAM that is less advanced than the performance specifications in the October 7 controls. If CMXT's intentions are sincere, then this is arguably a success story for the October 7 policy since CMXT had previously been planning to expand advanced node capacity. However, one industry analyst told CSIS that the composition of equipment purchases by CMXT is inconsistent with an intention of producing legacy DRAM chips and would make far more sense if CMXT's true intention was to produce chips more advanced than those prohibited by the October 7 end-use controls. If true, this would suggest that CMXT is deceiving U.S. companies and regulators in order to amass a stockpile of U.S. equipment that will at some point be redirected to restricted end uses. Another industry source told CSIS that CMXT is open with its Dutch and Japanese equipment suppliers about its intention to produce chips more advanced than those allowed under U.S. export controls.

The October 7 export controls—and especially the Dutch and Japanese restrictions—were too late to prevent SMIC from bringing online a facility that will likely soon achieve 35,000 WPM of 7 nm production capacity with decent, if not world-leading, yield. This is a genuine **threat** to U.S. and allied national security, not least because of what it likely means for the Chinese military's access to domestically produced AI chips.

The highest levels of leadership in both the United States and China—including Xi Jinping—**believe** that leading in AI technology is critical to the future of global military and economic power. In May 2023, a group of AI industry and academic leaders issued **a statement** warning that the risks of advanced AI should be viewed in the same way as pandemics and nuclear war. None of those risks will be any easier to manage if China achieves its vision of becoming an AI-enabled authoritarian superpower.

Potential Implications for China's AI and AI Chip Sector

Huawei's new chip and 5G phone attracted the bulk of the media attention during and after Secretary Raimondo's August 2023 visit to China. However, the more strategically important disclosure related to Huawei's progress on AI chips. On August 27, the chairman of iFlytek, one of China's largest and most technologically sophisticated AI companies, **said** at a conference that "I am particularly happy to tell you that Huawei's GPU capabilities are now the same as Nvidia's A100. [Huawei CEO] Ren Zhengfei attaches great importance to it, and three directors of Huawei have gone to work in iFlytek at HKUST [Hong Kong University of Science and Technology]. Now they have benchmarked against Nvidia's A100 [Google automated translation]."

In short, at the same time that Huawei was announcing its return to the 5G smartphone market, it was also announcing its return to the GPU (also known as AI chip) market. In contrast to more general-purpose processors, AI chips are specially designed to increase speed and reduce the power consumption of developing (referred to in the industry as "training") and operationally using (referred to as "inference") machine learning AI models.

Huawei has sold AI accelerator chips under its Ascend product line **since 2019**. These chips were designed by HiSilicon and manufactured by TSMC. This halted in May 2020 after the first Huawei FDPR rule. However, Huawei was rumored to have amassed a major stockpile of these chips, allowing the company to continue winning major data center contracts across China. Independent testing by Chinese university scholars in September 2022 **found** that that Huawei's Ascend chips were inferior to Western competitor products, most notably Nvidia, on nearly all performance metrics related to chip design and hardware.

However, in the case of Nvidia, its competitive dominance is based not only on the performance of its chips but also on the strength of the software ecosystem that is based upon Nvidia standards, particularly Nvidia's CUDA software ecosystem. CUDA makes it **much easier** for programmers to write massively parallelized software (as all modern AI software is) and ensures backward and forward compatibility so that older chips can still run newer software and vice versa. Any customer who seeks to stop using Nvidia chips has to leave the CUDA ecosystem, which requires solving a lot of incredibly hard software problems for which CUDA already provides free answers. Those free answers reflect billions of dollars of investment in the CUDA platform by both Nvidia and its customers.

The strength of the combined offering of CUDA software and Nvidia hardware goes a long way toward explaining why Nvidia accounted for **95 percent** of AI chip sales in China in 2022, according to estimates by Fubon Securities Investment Services.

Even in 2019, Huawei's strategy for competing with Nvidia in the AI chip hardware market included creating a software alternative to CUDA, which Huawei **refers to** as its Compute Architecture for Neural Networks (CANN). **According to Huawei**, "CANN is not only a software platform, but also a development system that includes a programming language, compilation and debugging tools, and programming models. CANN creates a programming framework based on Ascend AI Processors." Huawei **claimed** in September 2022 that Ascend and CANN were generating traction: "More than 900,000 developers have launched more than 1,100 AI solutions based on Ascend, which are widely used in government, telecommunications, finance, electricity, internet and other fields."

iFlyTek is one AI firm that has **close ties** to the Chinese government, including developing AI technologies used in the surveillance and repression of China's Uyghur minority. For this reason, iFlyTek was placed on the U.S. entity list **in 2019**. iFlyTek is therefore a natural target customer for Huawei's AI chips, since its access to U.S. alternatives is restricted. Prior to the entity listing, iFlyTek **primarily used** Nvidia products.

More recently, Huawei claimed in **July 2023** that the number of Ascend and CANN developers has doubled to 1.8 million. It is unclear how Huawei is measuring the number of Ascend and CANN developers or how active an average Ascend developer is. For comparison, Nvidia **said** in May 2023 that CUDA has 4 million active developers and that CUDA has been downloaded more than 40 million times, including 25 million times in just the past year. Despite the October 2022 export controls, Nvidia's chips that are legally approved for export to the Chinese market, the A800 and H800, are reportedly in **high demand** by Chinese hyperscale cloud computing vendors. The A800 and H800 are degraded versions of the A100 and H100 chips, respectively. Specifically, the A800 and H800 have equivalent processing power to their non-degraded counterparts but significantly **reduced interconnect speed** that is below the export control thresholds.

Nvidia's A100 models (launched in 2020) are manufactured by TSMC on their 7 nm process, while its H100 models (launched in 2022) use a **custom** TSMC 4 nm process node. Nvidia has not announced the release date for its forthcoming B100 product line, but it will **reportedly** use TSMC's 3 nm process node and launch in either late 2024 or early 2025.

All of this suggests that even Nvidia's products that are degraded to comply with export controls will be more attractive than Huawei's alternatives for at least the next few years. Huawei and SMIC do not have a clear path to producing chips beyond the 5 nm node, and SMIC will likely have poor unit economics to produce 5 nm chips without access to EUV technology. The greater maturity of the CUDA software ecosystem also makes Nvidia chips more attractive.

However, if the performance thresholds specified in the October 7 export controls are held constant, then the attractiveness of Nvidia products compared with Huawei alternatives could change significantly in the future. The current performance penalty for training large AI models with the degraded Nvidia chips is **reportedly** in the range of 10 to 30 percent. This is significant, but able to be overcome by Chinese AI firms that benefit from both government subsidies and a protected domestic market.

Industry sources told CSIS that the performance penalty will grow over time as the consequences of capped interconnect speed become more and more pronounced. This could potentially mean that Huawei chips, which would obviously not comply with interconnect speed restrictions, could have superior overall performance even if they are manufactured on an inferior semiconductor process node. Moreover, there are other sources of improvement to chip performance besides adopting a superior manufacturing process node. Nvidia's chief scientist Bill Dally recently **said** that of the 1,000-fold performance improvement that AI model training on Nvidia chips has undergone over the past 10 years, semiconductor manufacturing process node improvements were only the third most important factor. More specifically, he said that process node improvements had delivered a two-and-a-half times performance boost between the 28 nm node and 5nm node.

This suggests that—even if export controls were able to effectively constrain China's AI development to the 28 nm node as was their original intent—there are limits to how much export controls on Nvidia and related firms can degrade the performance of U.S. AI chips before Chinese firms will make an economically rational choice to buy domestic alternatives, such as those designed by Huawei, Biren, or Cambricon. Chinese AI firms would likely prefer a 28 nm Chinese chip over a 7 nm U.S. chip if the U.S. chips' interconnect speed limitations degrade AI model training performance more than the use of an older node degrades the Chinese chips' performance.

However, the 28 nm target might now be out of reach, unless the United States and its allies are willing to engage in dramatically more aggressive restrictions. If SMIC is able to build out Chinese domestic availability of 7 nm production capacity with adequate reliability and yield, that would significantly accelerate the timeframe in which Chinese AI development firms such as Alibaba and Baidu might find Huawei chips attractive in comparison to those of Nvidia. There are, of course, significant switching costs to leaving the CUDA ecosystem.

Along with the Chinese government and its corporate partners, Huawei is now engaged in a project to build a Chinese computing ecosystem that is entirely independent of the United States. The list of projects that Huawei and its partners have underway at varying levels of maturity is extraordinary. It includes at a minimum the following:

- **EDA chip design software**;
- **Chip manufacturing equipment**;
- **Chip manufacturing facilities**;
- **Chip designs** for personal computers, smartphones, and data centers;
- **AI chip enablement** software ecosystems;
- AI software development **frameworks**;
- **AI models**;
- Computer and smartphone software **operating systems**;
- Computer, smartphone, and data center **hardware** systems; and
- **Cloud computing**.

In much the same way that one of the first major initial uses of the Chinese yuan currency for international trade transactions was **avoiding U.S. sanctions**, the initial customer base for Huawei's alternative AI computing ecosystem is sanctioned and entity-listed actors in China. That may soon grow to include other countries such as Russia and Iran. Within China, entity-listed firms and government agencies comprise a larger and more technologically sophisticated customer base than is commonly understood in Western policy circles. iFlyTek, for example, has routinely published research papers at leading international AI conferences. Even after being sanctioned, iFlyTek has **40 percent market share** in China's automotive voice recognition market.

Beyond the Chinese domestic market, the other critical market for Huawei's technology stack is exports, especially to the global South.

The Need for Timely U.S. Intelligence Collection and Technology Analysis on China's Semiconductors

Perhaps the most surprising fact about the Huawei breakthrough is that so many U.S. government leaders were evidently surprised. Asked about the chip on September 6, National Security Advisor Jake Sullivan **stated** that "I'm going to withhold comment on the particular chip in question until we get more information about precisely its character and composition." Similarly, a group of Republican members of Congress **wrote a letter** to Department of Commerce leadership in which they expressed being "extremely troubled and perplexed" by what the Huawei phone suggests about the efficacy of U.S. export controls.

None of these statements give confidence that these U.S. leaders in either the White House or Congress are receiving good intelligence about the state of China's quest for semiconductor self-sufficiency. If this is indeed the case, it is simply unacceptable. It is possible, of course, that the U.S. intelligence community has more answers than the U.S. government is making public.

The October 7 export controls were one of the most important foreign policy moves that the Biden administration adopted in 2022, perhaps second only to supporting Ukraine against the Russian invasion. Senior U.S. national security and foreign policy leaders need to know to what extent that policy is having the intended effect, and they need to learn that before China **rubs it in a U.S. cabinet secretary's face** during a trip to China.

The Huawei phone and SMIC chip were not well-kept secrets. Reports of Huawei returning to the 5G market with a SMIC-manufactured 7 nm chip were already **widespread enough** in July of this year that Chinese industry executives were **publicly commenting** on it.

Hopefully, this incident merely reflects a failure of the relevant information to reach U.S. leaders and not a genuine gap in the capabilities of the U.S. intelligence community. During the Cold War, the U.S. intelligence community produced **exceptionally good analyses** of the Soviet semiconductor industry and the effectiveness of U.S. semiconductor export controls. Today, there are a host of critical questions about the Chinese semiconductor industry and the effectiveness of U.S. export controls where the U.S. intelligence community needs to supply senior U.S. decisionmakers with timely intelligence. Here is just a sample:

- Are SMIC or CMXT deceiving U.S. semiconductor equipment companies when they claim that post-October 7 equipment purchases are going to be exclusively used for production less advanced than the October 7 technology thresholds?
- How much advanced chip production capacity does SMIC intend to build out? At what technology nodes will this occur and over what timeframe?
- Does the Chinese government intend to pressure Chinese businesses and consumers to purchase Huawei smartphones and chips (and not to purchase U.S. alternatives) in order to drive economies of scale? If so, what will be the likely costs to U.S. firms in terms of lost sales?
- How are SMIC and YMTC getting spare parts to continue operating their advanced node U.S. equipment? Are they illegally diverting U.S. exports via shell companies or other tactics? Are they being supplied by foreign firms that manufacture viable alternatives? Or are there Chinese companies with adequate technology to supply them?

- Are reports that YMTC is close to restarting advanced production with improved Chinese domestic equipment alternatives true? Is YMTC also benefitting from equipment and components acquired in violation of U.S. export controls?
- How much technological progress have domestic Chinese equipment makers made, and in what areas? How much foreign help are they receiving, and from what sources?
- What level of Chinese government subsidization are Huawei and SMIC specifically receiving to support their advanced node manufacturing? Do the firms have a credible path to profitable 7nm products without government support? Is the Chinese government prepared to sustain or increase this support indefinitely?
- How has China's **crackdown** on foreign consulting firms impacted the ability of U.S. compliance companies to engage in substantive due diligence prior to selling to Chinese companies?

Conclusion: The Future of Export Controls

Limiting China's access to advanced AI chips is a highly desirable national security outcome. However, given the flaws and long timelines for how the Trump and Biden administrations have pursued export control policies, it is difficult to see how the United States could degrade China's current technological state of the art without dramatically expanding export controls and significantly increasing resources devoted to identifying and patching loopholes and strictly enforcing violations.

It is not clear, for example, that even a complete entity listing of SMIC with presumption of denial for all products would cause the SN1 and SN2 fabs to shut down. With the current staffing and budget given to the Department of Commerce for export controls, there are reasons to doubt that the U.S. government can identify shell companies at the rate that Huawei, SMIC, and their partners can create them. Only China-wide restrictions imposed simultaneously and without advance notice by the United States, Japan, and the Netherlands on multiple categories of exports, especially raw materials, would have a clear path to shutting down the SMIC fabs.

If SMIC has indeed been engaged in a massive campaign of export control evasion and has been providing false information to U.S. firms for their export license applications, then the case for such an option is stronger. It would provide strong evidence that China is already sprinting full out toward its own strategy for semiconductor decoupling without the slightest care of complying with U.S. law or preserving room for reaching an understanding with the United States.

In such a case, the United States might conclude that it is better for semiconductor decoupling to happen when it is inconvenient for China rather than wait for China to do it when it is more convenient and on China's terms.

But it will likely be more difficult to persuade U.S. allies to go along with such extreme measures if SMIC's achievement has been done entirely or almost entirely through equipment purchases made in full compliance with U.S. law.

What if SMIC has simply been exploiting legal loopholes in the Trump administration approach and taking advantage of the Biden administration's very slow onboarding of Japan and the Netherlands?

What if SMIC is sincere in its statements that the massive expansion of fab capacity that it is bringing online will exclusively be used for 28 nm production?

U.S. allies will be more willing to restrict the actions of their companies and citizens if they understand the evidence of reverse engineering and illegal purchases of equipment, as well as how China's plans are not in their own national interest. This underscores the need for timely and high-quality intelligence.

There are other aspects of this story where SMIC could be in violation of U.S. law besides whether SMIC's post-October 2022 equipment purchases were intended for 7 nm manufacturing. The FDPR **as applied to Huawei** has thus far restricted the ability of firms that use U.S. equipment to produce chips on behalf of Huawei, regardless of when that equipment was purchased. The rule, as written, also includes coverage of more than exports, including in-country transfers (such as the SMIC's sale of chips to Huawei). A group of U.S. members of Congress sent a letter to the Department of Commerce directly **alleging** that SMIC's production on behalf of Huawei was in violation of U.S. export controls. As mentioned above, this does indeed seem to be the case.

The U.S. government's response will have to take this into account. After all, if the United States fails to respond to export control violations by Chinese entities, firms in Taiwan, South Korea, Europe, and elsewhere will feel they are being unfairly treated when the U.S. government requires them to comply.

One area where it makes obvious sense to expand restrictions is in preventing U.S. and allied companies from supporting the maturation of Chinese equipment and component companies. There is little strategic sense in allowing U.S. and allied companies to help China to prepare for decoupling with the United States and its allies. It is not in South Korea's national interest, for example, for South Korean equipment and spare parts firms to aid China's equipment indigenization effort. Nor is it in South Korea's interest to allow South Korean consultants to train Chinese engineers on how to improve the yields of their memory production fabs. Both of these will inevitably be used to break South Korea's leadership in semiconductor manufacturing.

Similarly, the United States and its allies need to crack down on third-party sales of spare parts and components.

In the absence of good intelligence, however, the United States will continue to be faced with an undesirable choice between taking strong action early enough to have an impact (but in a way that might seem premature or unjustified to allies) or on the other hand waiting until the justification is clear, at which point it might be too late to have an impact in the wake of Chinese equipment stockpiling and indigenization campaigns.

This is the same unattractive choice that the United States has faced again and again since the Trump administration began using semiconductor export controls as a tool of foreign policy in 2018. Thus far, the United States has chosen repeatedly to enact export controls that are threatening enough to incentivize Chinese firms to stockpile and to de-Americanize their supply chains, but not strongly enough written or enforced to prevent China from succeeding in their indigenization and stockpiling efforts.

The United States has incurred essentially all of the costs of an aggressive export control policy toward China, but it has done so in a way that does not provide all the potential strategic benefits of actually constraining China's future technological capabilities. The U.S. and allied approach does appear to have limited China's access to nodes more advanced than 7 nm in economically competitive terms and more advanced than 5nm in absolute terms.

It is possible that China's extremely expensive efforts to indigenize everything will prove to be a strategic error: forcing China's government to perpetually subsidize an **often-corrupt** semiconductor industry that produces products that are uncompetitive in Chinese or global markets. Such was the case with the Soviet semiconductor industry.

However, it is also possible that China's domestic champions will ultimately achieve some degree of financial sustainability, driven by partially or fully protected sales in the large Chinese home market as well as successful exports abroad. Such was the case with China's automotive and solar cell manufacturing industries.

Imposing these costs upon China is not without strategic value, both in terms of slowing its military development and in preserving U.S. technological leadership. Ben Thompson of Stratechery **argues** that China's obsession with achieving 7nm production in violation of U.S. export controls may actually slow China's overall technological development: "Every year that China stays banging its head on the wall at 7nm instead of focusing on moving down the learning curve from a fully indigenous .13 micron process to 90nm to 65nm to 40nm to 28nm to 22nm to 16nm to 10nm to 7nm is another year that China doesn't break the 5nm barrier."

In a similar argument, *Bloomberg*'s Tim Culpan argued that the Huawei chip shows that U.S. curbs "are porous, not useless."

Still, this will be an unsatisfying outcome for those who hoped for more from the October 7 policy. Export controls as a tool rarely deliver perfect solutions, especially not with regards to countries as large and technologically advanced as China. To the extent that export controls worked against the Soviet Union during the Cold War, it was because there was so little economic engagement between the camps to begin with and because they were so broadly enforced. To the extent that export controls worked after the Cold War, it was because the aims were quite limited and because even governments that could agree on little else could agree that they were opposed to terrorists and rogue states acquiring nuclear weapons.

Trying to draw neat export control lines that achieve ideal and durable technological outcomes for dual-use technologies in the U.S.-China relationship is significantly more difficult. Broader controls, especially multilateral ones, have a better chance of success, but the political coordination and enforcement challenges are still difficult. The United States has imposed significant costs upon China, but not so significant that they have changed the Chinese government's position on issues such as military AI development, human rights violations, sanctions violations, or intellectual property theft. Rather than change its ways, China is now spending hundreds of billions of dollars to decouple itself from multiple parts of the U.S. semiconductor and related technology ecosystem.

Beginning in 2018, the United States has imposed costs upon China that are severe enough to persuade China to accelerate the indigenization of its semiconductor supply chain, but the United States and its allies have not—at least thus far—implemented export controls that are tight enough and multilateral enough to definitively prevent China from succeeding in indigenizing. Previously, the United States allowed Huawei to stockpile U.S. chips before cutting Huawei off. More recently, the United States has allowed Chinese chip fabs to stockpile U.S., Dutch, and Japanese equipment before imposing broad restrictions on the sale of such equipment. Even now, China is still acquiring significant technology and knowhow from South Korean and other firms.

These are all enormous shifts underway, and the future is far from certain. What is clear, however, is that the existing export controls need to be expanded to include South Korea, Germany, and ideally the entire European Union. It is also clear that U.S. allies need to strengthen their export control regimes to be effective, which means creating legal authorities that restrict knowledge transfers and the actions of overseas subsidiaries.

Finally, it is clear that all allied governments need improved intelligence and improved economic and technological analytic capacity as well as improved export control enforcement capacity. Even though export controls are central to U.S. foreign policy toward both Russia and China, Congress is now **poised to deny** the Department of Commerce's export controls bureau its meager **request** for funds needed to keep a flat budget after accounting for inflation. This is, in real dollar terms, a budget cut–and a shocking error given how much of U.S. national security and economic security now depends upon the efficacy of the U.S. export controls system.

Even if the future will often be foggy, the U.S. government must be willing to invest heavily in an improved ability to see clearly and to act effectively. ■

Gregory C. Allen *is director of the Wadhwani Center for AI and Advanced Technologies at the Center for Strategic and International Studies in Washington, D.C.*

This report was made possible by generous support of CSIS as well as the Survival and Flourishing Fund.