FEBRUARY 2024

Balancing the Ledger

Export Controls on U.S. Chip Technology to China

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An initial assessment of recent attempts by the United States to limit or delay China's ability to acquire and produce advanced semiconductor technologies reveals a mixed picture in a complex and rapidly evolving industry. On the one hand, new chip restrictions have significantly affected China's semiconductor ecosystem, limiting access to equipment essential for next-generation production. On the other hand, China is intensifying its domestic investments in more advanced chips while also reducing market shares of U.S. firms—and by extension, the revenues U.S. firms need to invest in the next-generation of technology. Over time, this loss of market share could well undermine the competitiveness of U.S. firms in this key industry. The initial volley of restrictions has also revealed limitations of export controls, both because the technology is rapidly changing and because there are gaps in compliance between U.S. companies and those of allies.

One key conclusion, however, is that there is "no way back" to the global semiconductor ecosystem that existed prior to the pandemic. The U.S. chip supply chain vulnerabilities that the Covid-19 emergency exposed are too alarming to allow a reversion to a business-as-usual supply chain anchored in China. Further, Chinese perceptions of the United States' reliability as a supplier have understandably changed. It is unlikely that U.S.-China semiconductor-related trade will return to the *status quo ante*.

While the United States retains a substantial lead in semiconductor design and certain equipment, the most advanced chips are no longer manufactured by U.S.-based firms. This has troubling implications for new technologies such as artificial intelligence (AI) and quantum as well as for the security of supply for key industrial inputs. The Biden administration is to be commended for recognizing the central importance of the industry, its vulnerabilities, and the fact that the industry has been both challenged abroad and neglected at home. As the world enters a period of renewed policy focus on this enabling technology, it is important that the government's analytic capabilities are improved to inform policy, develop effective mechanisms for allied coordination, and create the government-industry partnerships and long-term investments that will be needed to sustain and grow a more resilient U.S. semiconductor ecosystem.

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A Cascade of U.S. Export Control Actions

On October 7, 2022, the Department of Commerce's Bureau of Industry and Security (BIS) **announced** dramatic revisions to its **export controls** on semiconductor technology, intended to foreclose China's ability to obtain high-end semiconductor chips, technology, manufacturing equipment, and know-how. These restrictions were **substantially tightened** on October 17, 2023, as the Department of Commerce finalized its proposed U.S. export control rules. The consequences of these restrictions have been far-reaching and their impacts on the semiconductor industry are only now coming into view.

The restrictions were not, however, an isolated act. They follow in the wake of a 2019 ban by the administration of President Donald Trump on U.S. companies' delivery of goods and services to Chinese telecom equipment maker Huawei without export licenses, effectively cutting off Huawei's access to key U.S. semiconductors. Reflecting a growing policy consensus, President Joe Biden tightened these **restrictions** in 2022.

In addition, the Biden administration has further restricted outbound investment. In a major move, on August 9, 2023, President Biden signed an executive order to create a mechanism for restricting outbound investment in the semiconductor, quantum information, and AI sectors in foreign "countries of concern," a designation that includes China. The Department of Treasury, responding to the executive order on outbound investment, is preparing to establish outbound restrictions on U.S. investments in **Chinese AI** sectors critical to military, intelligence, surveillance, and cyber-enabled capabilities. Other restrictions are likely to follow.

The U.S. government cites national security grounds for these restrictions, which are straining relations with the domestic chip industry, U.S. allies, and China. A Department of Commerce official **commented** in October 2023, "The PRC government is attempting to divert a lot of civilian technologies, particularly in computing, space, AI and communications, into areas of supercomputers in civil-military fusion programs as well as other areas such as surveillance that link with human rights abuses." The export controls are characterized as a direct response to this unique and far-reaching challenge from what some see as a "near peer" power bent on surpassing the United States by whatever means possible. While facing pushback from U.S. companies and allies, the Biden administration is nonetheless pursuing a policy of limiting China's access to the most advanced chips and the tools to produce them. The policy is envisioned over a five-year time frame or longer. "It's a grand vision," Secretary of Commerce Gina Raimondo **says**, "five or six years . . . we will have achieved a lot of that."

The Central Role of U.S. Allies

Will U.S. allies follow the United States' lead in restricting the movement of advanced technologies to China? U.S. allies are in the process of imposing **parallel restrictions**, perhaps most importantly Dutch and Japanese limits on the export of advanced lithography equipment to China. However, the allied response to date has been characterized as "**piecemeal**," and the dissonance between U.S. and allied systems of export control leave substantial holes in the restrictive net envisioned by U.S. policymakers.

Indeed, the success of U.S. controls is likely to depend on the ability to harmonize U.S. restrictions with those of key allies, whose export controls differ substantially from those of the United States, resulting in substantial gaps. In general, U.S. allies have a narrower scope for restrictions.

- While BIS maintains an "entity list" of foreign companies and other entities barred from procuring designated technologies, Japan does not have a similar list; instead, it has merely designated 23 types of technology that require an export license. Importantly, and in contrast to U.S. controls, Japan does not explicitly designate China as a country of concern.
- Similarly, the Netherlands is the source of the most critical production equipment and holds a virtual monopoly. Yet Dutch export controls are limited to a small number of products and do not identify China as a country of concern.

In addition, semiconductor firms in Japan, South Korea, and Europe operate in a different part of the semiconductor ecosystem, have **different commercial interests**, and do not necessarily share U.S. views of strategic competition. U.S. allies in Europe and Asia have not replicated the extraterritorial application of U.S. controls, which means that if their companies wish to continue trading with China, they may do so by establishing overseas subsidiaries. Moreover, EU decisionmaking is enmeshed in cumbersome procedures. While the European Commission **is seeking** the authority to impose export controls on key technologies, including semiconductors, progress is likely to be slow, as all 27 member states must approve the grant of such authority. This level of consensus may well prove difficult, especially in a relevant time frame.

Impact of Controls on China

Whatever the imperfections of U.S. and allied export controls on chips, the current restrictions appear to have a significant impact on China's semiconductor ecosystem. The Dutch decision to block exports of ASML's most advanced extreme ultraviolet (EUV) lithography tools should, in principle, foreclose China's ability to produce advanced chips at the two- and three-nanometer nodes. These advanced chips are needed to sustain China's AI development. Currently, China simply **cannot replicate** ASML's lithography technology: "Producing this kind of complex machinery entirely within China is not likely to happen in the foreseeable future," industry insiders say.

Further, China's most advanced maker of semiconductor lithography equipment, the government-run Shanghai Micro Electronics Equipment, announced in the summer of 2023 that it would start delivery of lithography equipment capable of manufacturing chips at the **28-nanometer** node, "well behind the industry's cutting-edge of 2 to 3 nanometers." For the foreseeable future, most Chinese companies will be relegated to the production of higher-node, sometimes called "legacy" chips, though this shift, fueled by very substantial state-backed investments risks posing significant challenges to Western production systems and profitability.

More broadly, China's advanced tech development efforts appear to be impaired by the loss of access to high-end U.S. semiconductor devices.

- For example, Nvidia's leading-edge A100 and H100 chips are among the most critical tools in the AI industry. These devices feature built-in infrastructure for training AI models and algorithms, including computer vision, natural language processing, and conversational AI, and are now **banned** from export to China. The U.S. government has required Nvidia to stop shipping some of its high-end **AI chips** to China without licenses.

- Japan's highly targeted restrictions on exports of chipmaking tools, in which Japan holds a near or total monopoly, are expected to impede Chinese chipmaking not only in the advanced nodes but in **capacity expansions** for 14- and legacy 28-nanometer nodes as well.

While the overall effect of these restrictions is not yet clear, they appear to be having significant impacts on some Chinese companies.

- China's largest chipmaker, Yangtze Memory Technologies Co (YMTC), was reportedly hit hard by Western restrictions on chipmaking equipment and is laying off **10 percent** of its workforce.
- In February 2023 China's largest semiconductor foundry, Semiconductor Manufacturing International Corporation (SMIC) warned that mass production at its new **$7.6 billion** plant might be postponed by one to two quarters as a result of "difficulties in securing key equipment" in the wake of Western export controls.
- The restrictions have sparked sharp price increases among mainland consumers of Nvidia's GeForce RTX 4090 graphics card in the wake of Nvidia's October 19 decision to limit its Chinese distribution of this popular product, which is used by video game and graphics designers. At some Chinese third-party online stores, the 4090 costs between around $5,500 and $6,900, **triple** the Nvidia price. But one should note that these are essentially consumer, not strategic, impacts.

The Chinese Response

China is responding to U.S. moves to block advanced technology transfers by upping its own game in a number of ways:

- **A pivot at scale.** The Chinese government is **reportedly** "pouring money into advanced chip technology research and development" and supporting a pivot by domestic manufacturers to a focus on higher-node chips with myriad applications across the economy and in new sectors such as electric vehicles (EVs). In 2022 the Chinese government reportedly gave 190 listed chipmakers **$1.8 billion** in direct subsidies and additional (unknown) loans and equity investments in nonlisted firms.
- **Massive state support.** The central government is investing far larger amounts indirectly via state-backed entities such as the National Integrated Circuit Industry Investment Fund Company, established in September 2014 and known colloquially as the "Big Fund." Recent investments by state-backed entities in national champion chipmaker YMTC have reportedly totaled **$7.1 billion**. In January 2023 the Big Fund and an "unnamed 'Wuxi entity'" announced that they would invest **almost $2 billion** to fund the construction of a 12-inch wafer fab in Wuxi by Chinese chipmaker Hua Hong to manufacture legacy chips. In October 2023 the Big Fund **contributed** a $2 billion investment to hold a one-third stake in memory chipmaker Changxin Xinquao.
- **Joint funding by central and regional governments.** Investments by the central government of China in the semiconductor industry are being augmented by subsidies from provincial and local governments. Thus, in early 2023 the government of Jiangsu Province committed **$74 million** a year to chip firms to help finance research, equipment purchase, chip design, and packaging. Jiangsu will also provide cash grants to local universities for semiconductor-related programs.

- **Circumventing export controls.** Chinese companies have proved **extraordinarily adept** at circumventing Western export controls, having "many ways to dodge export controls, such as third-party partners, offshore entities, or other shell companies." In some cases, "parts are simply snuck across borders," such as by attaching extra chips to printed circuit boards. A semiconductor supply chain executive **observes**, "They assume no custom officers will know if there are many more parts on such printed circuit boards [than there should be]. Also, it requires massive efforts to open every box to check." Another approach is to mark the shipments of precision components as waste parts to get through customs. After these parts enter China, they can be remarked and repackaged. Chinese companies are also creating numerous shell companies faster than the DOC can track them. An executive at one chip equipment maker **says**, "We found some Chinese companies now quite fancy changing names constantly. Last quarter their name is this one, next quarter it changes to a different name." These efforts, at least anecdotally, have proven successful. As recent as January 2023, Chinese military and affiliated institutions **have purchased** Nvidia's most advanced H100 chips from sources within China in small batches, suggesting an unknown quantity of controlled chips are making their way into China.
- **Building stockpiles.** Chinese chipmakers have been on a shopping spree to acquire Dutch and Japanese semiconductor manufacturing equipment, taking advantage of the long hiatus before those countries' export controls fully take effect. U.S. exemptions from the controls are also enabling Chinese firms to acquire U.S. chip tools. According to one source, the United States is simply allowing various equipment companies to ship tools with a license. Some observers **argue**, "The U.S. is granting licenses like they're candy." These broad and multivariant exemptions can and will undermine the impact of current and future controls.
- **Building technological infrastructure.** China's Tsinghua University has announced a plan to bypass Western restrictions on lithography machines by building a particle accelerator with a circumference of 100–150 meters. The accelerator's electron beam is expected to serve as a high-quality light source for on-site chip manufacturing, and the plan is to build a "**colossal**" factory housing multiple lithography machines arrayed around the particle accelerator. The expectation is that eventually this project will enable China to manufacture two-nanometer chips in high volume.
- **Driving new Chinese innovations.** Chinese entities have announced significant microelectronics innovations since the allied sanctions were imposed. In October 2023 Chinese scientists from Tsinghua University **announced** the development of the world's first fully system-integrated memristor chip, with significant applications in AI and autonomous driving. In September 2023 the China Electronics Technology Group (CETG), a major Chinese defense manufacturer, announced it had **developed** a gallium nitride radar chip with a record power output "using semiconductor technology that is the subject of U.S. sanctions."
- **Making technological progress despite sanctions.** Huawei has startled industry observers by launching a new smartphone, the Mate 60 Pro, incorporating an allegedly indigenously developed 5G modem, possibly indicating that China enjoys a higher level of technology development capabilities than previously assumed. U.S. commerce secretary Gina Raimondo characterized Huawei's success as "**disturbing**."
- **Exploiting export control gaps.** The seven-nanometer chip used in Huawei's 5G phone was **widely reported** to have been developed by China's SMIC, its largest semiconductor foundry,

using deep ultraviolet lithography (DUV) systems. According to one source, SMIC's ability to produce the seven-nanometer device was not based on Chinese indigenous innovation but on its ability to acquire the necessary foreign equipment despite U.S. sanctions, reflecting **multiple gaps** in the Western export control regime: "As long as SMIC has access to advanced deep ultraviolet (DUV) lithography technology from ASML and wide access to other critical advanced tools from American vendors, it can produce 7-nm chips at scale." ASML revealed in its 2022 annual report released in February 2023 that "one of its **China-based employees** had engaged in 'unauthorized misappropriation of data relating to proprietary technology' that may have breached some export controls." The Dutch newspaper NRC reported that the perpetrator went on to work for Huawei after leaving ASML.

- **Pulling in talent.** China has quietly revived the Thousand Talents Plan (TTP), a program designed to attract foreign scientific and technology experts, which was terminated in 2018 in the wake of U.S. investigations. The new program **operates** under a different name, *Qiming*, and seeks to recruit foreign and overseas Chinese PhD-level experts from "sensitive" and "classified" sectors including semiconductors. The new program features incentives such as subsidized housing and signing bonuses ranging **from $420,000 to $700,000**, essentially providing in a short time frame the equivalent of an end-of-career salary for middle-aged engineers well versed in the critical tacit knowledge needed for advanced semiconductor production.

Significantly, China is also taking measures to disrupt the U.S. semiconductor industry and signaling what it could do if pressed further by Western technology restrictions:

- **Cutting market share of Western firms.** In May 2023, **China declared** that U.S. memory chipmaker Micron Technology had "failed its security review" and barred Chinese operators of key domestic infrastructure from purchasing Micron products.
- **Restricting critical materials.** In July 2023, China **imposed** licensing requirements on exports of the rare-earth metals gallium and germanium as well as several compounds made from those metals, which are key materials in semiconductor manufacturing. These requirements could easily become a mechanism to reduce access to these materials.
- **Pushing design-outs.** China is continuing its **long-standing efforts** to induce domestic chip consumers to exclude U.S. chips and chip designs in their purchasing decisions.
- **Blocking foreign industry growth.** China is impeding U.S. semiconductor mergers and acquisitions by withholding regulatory approvals. In August 2023, Intel and Israeli contract chipmaker Tower Semiconductor scrapped a **$5.4 billion** deal pursuant to which Intel would acquire Tower after failure to gain approval from Chinese regulatory authorities.

Limits of Export Controls

In the face of these actions by China, some critics suggest U.S. restrictions could be rolled back. But, as noted, it seems much more probable that there is no way back to the global semiconductor ecosystem that existed prior to the pandemic. The U.S. chip supply chain vulnerabilities revealed by the Covid-19 emergency are too alarming to allow reversion to a business-as-usual supply chain anchored in China. Moreover, Chinese perceptions of the United States' reliability as a supplier have understandably changed. It is unlikely either side will be willing, or allowed, to return fully to the previous supply chain.

The realignment of microelectronics supply chains for resilience and security, instead of purely for efficiency, will inevitably modify, and perhaps damage, existing innovation networks and complicate the operations of semiconductor companies. This is already happening: for example, the large chip fabrication plants Western firms have established in China with tens of billions of dollars in investment are already being **affected** by new export controls and are now hostage to the vagaries of the U.S.-China chip rivalry.

The impact of these developments on revenue for some U.S. equipment companies is significant, with the attendant risk of long-term impacts on the research and development (R&D) that underpins their competitive position. Similarly, China is reducing access to its domestic market for some U.S. semiconductor companies, which will negatively impact the ability of these U.S. companies to invest in new facilities and equipment. The hard truth is that U.S. companies are competing under a new set of circumstances with what is, for many, their largest customer.

Indeed, the notion that the United States and its allies can significantly slow Chinese capabilities in microelectronics is a hypothesis—nothing more—and the events of 2022 suggest Chinese capacities are far from static. They will need to be continuously reassessed in light of ongoing indigenous developments. China's use of institutional "technology extractors" (such as local content requirements, joint ventures, and technology-for-market-access deals) to acquire foreign technologies is extremely skillful and these practices have continued to expand since the country's accession to the World Trade Organization (WTO) in 2001, notwithstanding its commitments in its protocol of accession and Western export controls. According to one estimate, in the first decade after accession, the number of identifiable technology extractors jumped from **53 to 339**, involving over 100 industrial sectors.

Against this background, China has proved to be skilled at acquiring foreign semiconductor technology, chips, and manufacturing equipment, including proscribed items, export controls notwithstanding. The slow implementation of the most recent round of allied export controls has enabled China to acquire Western equipment subject to controls—perhaps the most dramatic manifestation of which was SMIC's ability to secure European and U.S. equipment to manufacture chips for Huawei's new smartphone. Highly regarded former TSMC vice president Burn J. Lin said in October 2023 that SMIC should be able to advance to manufacturing chips at the **five-nanometer node** using the same equipment. While yields may be lower and costs higher than with advanced Western equipment, firms backed by low-cost capital and with preferential access to national markets, can and likely will remain formidable competitors in global markets.

Historically, China has proved to be unable to develop significant microelectronics innovations on its own, which quite possibly remains the case today. At the same time, the recent developments noted above suggest this dynamic may be changing, aided by leaky controls and systemic theft. In any case, complacency regarding the limits of Chinese capabilities may not be justified.

China's Dilemma: Autonomy versus Cooperation

Traditionally, Chinese policymakers viewed **continuous acquisition** of foreign chip technology as a *sine qua non* for the development of its own semiconductor industry. Thus, in 2000, then-minister of information industry Hu Qili **noted** that South Korea's three major semiconductor enterprises

> built up their fortunes on their cooperation with the United States and Japan. . . . If we just engage in development behind closed doors, totally rely on ourselves in the aspects of talented people, funds, and technologies, and produce products only to serve and support ourselves, it is absolutely impossible to establish ourselves in the intense international competitions.

On the one hand, China has sought to draw in foreign firms with advanced technology to complement its own efforts:

- **Acquiring foreign technology.** China's massive semiconductor industry **promotional effort** launched in 2014 **focused on** acquiring foreign companies, purchasing foreign technology, and recruiting foreign semiconductor talent. A Taiwanese observer commented in 2015,

  > Chinese authorities . . . aim to create world-leading semiconductor firms in terms of technology. But the country's semiconductor firms are mostly lagging behind their international competitors technology-wise, and the hard reality is that it would be very difficult for China to catch-up through its own research and development efforts. Buying existing firms with advanced technology instead of developing its own seems a quick fix.

Some progress was made, but the new CFIUS controls and similar measures among like-minded states have virtually closed this option.[1]

- **Slow progress on filling the equipment gap.** Despite these sustained national efforts, China's semiconductor manufacturing equipment industry is severely underdeveloped, and the country's abiding dependency on foreign equipment represents a major long-term vulnerability highlighted by the newly tightened Western export controls. The national chip equipment localization rate **was not even at 8 percent** as of 2021. A former vice president of the National Integrated Circuit Industry Investment Fund **commented** in 2018, "Chinese equipment and materials companies are so backward that it is even difficult to find proper investment targets." Despite the urgency of upgrading Chinese chip equipment capabilities, the national semiconductor investment funds have committed only about **0.4 percent** of their total semiconductor investments to the equipment sector, perhaps because policymakers assume China can readily acquire foreign equipment despite Western controls.

On the other hand, it is prudent to consider the real possibility that the new Western controls will drive Chinese policymakers and businesses to undertake truly indigenous innovation in microelectronics and that such efforts could lead to technological breakthroughs that could transform the global chip industry.

Indeed, China's government remains determined to catch up with the West in microelectronics. The 20th National Congress of the Communist Party report, released soon after the U.S. announcement of

1 "Pressure from China to Ease Semiconductor Restrictions," China Post, November 1, 2015. This article is no longer available online.

tightened export controls in October 2022, identifies the **trade conflict** with the United States as the "economic main battlefield" and promises "high-level technology self-strength and self-independence."

- **Investments and "design out."** In 2023 the Chinese government launched a new **300 billion yuan** ($41 billion) fund for investments in the semiconductor industry on the heels of 200 billion yuan ($27 billion) in 2019. Investments by the central government are being augmented by provincial and municipal governments. The city of Guangzhou committed over **$21 billion** in 2023 to enable Chinese chip consumers to eliminate foreign devices from their systems in favor of domestic chips. Chipmakers who operate at more advanced nodes than 28 nanometers qualify for a 10-year tax exemption **pursuant** to the State Council's "Policies to Promote the High-Quality Development of the Integrated Circuit and the Software Industry in the New Period." Importantly, these sums dwarf the resources of the "chips acts" in the United States and Europe.
- **The 2025 guidance and growing capabilities.** The government has established an aggressive road map for the semiconductor industry once again, this time pursuant to its "Made in China 2025" guidance. Reflecting long-term government objectives for greater autonomy in semiconductors, the plan envisions **80 percent localization** of Chinese consumption of chips by 2030 (the ratio was about 24 percent in 2020). Many of these targets have not been achieved in the past and may in part be aspirational. Nonetheless, the government may be **expected** to allocate major resources to at least work toward this target, and that commitment of resources and related trade measures may well negatively affect the market shares of U.S. producers.

Generating New Asymmetrical Capabilities

Western export controls have reportedly resulted in **pushback** by listed Chinese companies, "prompting them to increase their investment in R&D to enhance their technological innovation capabilities." The growing innovative capability of Chinese companies has recently been acknowledged by the Boston Consulting Group, whose annual roster of the **top 50** innovating companies in the world now includes Chinese firms such as Alibaba, Lenovo, Huawei, Xiaomi, JD.com, and Tencent. China's leading chip foundry, SMIC, has already demonstrated what is achievable, having narrowed the gap with world-leading semiconductor firms from trailing several generations behind in 2000 to several years behind at present.

China is innovating in microelectronics along multiple fronts, not just feature size. It is undertaking large asymmetrical, potentially disruptive projects, such as Tsinghua University's effort (noted earlier) to pioneer new forms of particle accelerator-based lithography, which could lead to leapfrogging of Western ultraviolet-based lithography technologies. China is also reportedly planning to build chips around alternative architectures such as the open **RISC-V system**, "which is free and open-source, [and] provides a faster and cheaper alternative to design and manufacture chips without relying on Western technologies." Similarly, Tsinghua researchers **published** a paper in *Nature* in October 2023 on a breakthrough experimental photoelectronic analog chip for computer vision that outperformed state-of-the-art computing processors by three orders of magnitude in terms of systemic energy efficiency and by one order of magnitude in terms of computing speed. It was fabricated on a 180-nanometer process, which may be just as significant as its performance.

- **Chiplet innovation.** Chinese enterprises are also utilizing **chiplet** technologies originally acquired from the United States to package groups of small semiconductors—sometimes no larger than a grain of sand—into powerful integrated units capable of wide-ranging applications.
- **Leveraging the legacy gap.** While it often seems underappreciated in U.S. policy discussions, "**Legacy chips** are at least as critical as advanced chips both in terms of economic importance and national security." Chinese firms already excel at the efficient production of these higher-node chips, which account for most of global semiconductor consumption, and Chinese chipmakers may be expected to innovate with respect to these chips to enhance their durability, decrease power consumption, and reduce costs without further access to Western technology. China has dramatically increased its investments in legacy chipmaking since the announcement of U.S. export controls in 2022. According to **some estimates**, China may build more legacy chip fabrication plants in the next few years than the rest of the world combined.
- **Absorbing efficiency trade-offs.** A U.S. semiconductor equipment engineer **notes**,

> It's not entirely impossible to use less-advanced tools to make more advanced chips. It's very difficult to have a clear cutoff on what machine can do what . . . The differences very often depend on how precise and how uniformly the work they could perform, and what are the throughputs, or efficiency, of those tools.

But efficiency is essentially a U.S. criterion. A fundamental difference between U.S. and Chinese chip manufactures is that U.S. manufacturers need to—indeed must—generate profits, usually on a quarterly basis. Chinese manufactures, with heavy and ongoing state support, are not constrained in the same manner. Companies that can compete without regard for losses are formidable competitors.

In sum, the recent innovative developments and workarounds in China's chip ecosystem are concerning. The Biden administration has embraced the term "**small yard, high fence**" to explain its technology controls affecting China—in other words, the universe of restricted technologies will be comparatively small, but the restrictions will be extremely stringent. But realizing this objective presents a formidable challenge. China's "yard" of advanced chip technologies with national security implications is expanding rapidly in a sprawling fashion—in multiple, often poorly understood directions. Moreover, the Western "fence" is currently full of holes, not least because of the lack of full congruence between U.S. and allied export control regimes. For these reasons, the concept of a "small yard, high fence" must be regarded as aspirational and certainly not a near-term reality.

The U.S. Faces Its Own Challenges

Regardless of the difficulties of controlling high-tech exports to China, the U.S. innovation system itself is vulnerable. Additional policy measures and investments are needed in many areas, not least in the semiconductor space. Competing with China will require substantial and sustained investments, not always a strong point for the United States.

THE NEED FOR SECTORAL EXPERTISE IN POLICYMAKING

One glaring vulnerability in the chip sector is the paucity of relevant government expertise in U.S. and allied countries with respect to both the commercial and defense-related aspects of particular semiconductor technologies. The **result** is that "relevant agencies often lack the expertise to assess

exporters' requests for a licence to sell products abroad." BIS has under 600 employees and an annual budget of about **$200 million**, resources that are simply inadequate to address the agency's many responsibilities. Absent an increase in the quality and depth of expertise to inform policy decisions, allied controls risk being ineffective. Recruitment of qualified staff with the necessary remuneration levels is essential. Direct and recent experience is critical for informed decisionmaking.

THE NEED FOR INFORMED ADVISORY COMMITTEES

The United States has in the past made episodic efforts to establish advisory bodies to guide semiconductor industry policymaking, and U.S. departments, agencies, and National Laboratories possess substantial internal expertise on specific themes. However, there is no central standing body of relevant expertise and data gathering and analytic capability to advise the Department of Defense or the Department of Commerce in real time with respect to what are often highly technical U.S. policy decisions on export licensing with wide-ranging implications.

- The United States **established** and funded the National Advisory Committee on Semiconductors in 1988 to advise the government on chip policy, but it lacked a secretariat and gradually faded into irrelevance, ceasing operations in 1992.
- The President's Council of Advisors on Science and Technology (PCAST) **releases** periodic reports on high-level policies in the semiconductor industry but does not represent a source of ongoing ground-level technical advice with respect to complex and frequently arcane semiconductor technologies.
- Federal departments, the National Institute of Standards and Technology (NIST), and the National Laboratories possess extensive expertise in specific aspects of semiconductor technology, but it is difficult for the Department of Commerce and the Department of Defense to access this knowledge in a comprehensive manner to assess export licensing requests in real time.

There is a positive precedent, however. In the late 1980s and early 1990s, the Sematech research consortium convened large numbers of scientists and engineers from industry, government laboratories, and academia to develop a technology road map for the semiconductor industry. This ad hoc effort succeeded beyond all expectations and was carried forward in Sematech's organic technical advisory bodies. While successful, this **advisory body** eventually became something of a one-off effort after the withdrawal of government support for Sematech and did not result in establishing a permanent advisory body that could provide technical semiconductor expertise to the government.

However, the working groups from industry, government, and academia that flourished under Sematech's auspices **remain a possible model** or starting point for an effective U.S. chip advisory brain trust. Importantly, the proposed National Semiconductor Technology Center (NSTC) has a major opportunity to fill this gap on an ongoing basis. The potential value of the NSTC will be its ability to provide long-term guidance based on close consultation with industry on how the needs of the industry can intersect with national security needs. Providing a long-term view with frequent level setting by advisory groups will be essential to its success.

COMPLEXITY AND COOPERATION

Although the United States and its allies are determined to strengthen the durability and security of semiconductor supply chains by separating them from China, it is important to recognize that those

chains are an enigma, even to companies embedded within them and to the end users they serve. The complexity is daunting. Chip **supply chains** often involve tens of thousands of companies in network arrangements that are many layers deep and constantly changing. Understanding them is difficult because most entities in this network want to keep the identity of their suppliers confidential. This means an original equipment manufacturer (OEM) that sources directly from several hundred equipment and materials vendors may have no idea who supplies those vendors or in what country these suppliers—and their suppliers in turn—are located. Some analysis suggests many of these vendors are East Asian. This complexity and opacity mean it is very hard to target policies to reward or isolate particular actors within this system. Moreover, policy actions are likely to have unexpected and often counter-intentional outcomes, potentially harming U.S. commercial and national security interests.

MAPPING SUPPLY CHAINS

If the objective is to facilitate disentanglement of U.S. chip supply chains from China (assuming that is possible and desirable), it would be imperative to develop public-private partnerships between U.S. government and industry to map out supply chains and develop ways to ascertain from where key inputs are coming. Bringing industry together to discuss supply chains will be—to use a modest word—difficult. To paraphrase a Chinese saying, extracting this information from the semiconductor industry will be "like pulling the teeth from the mouth of a tiger." Even so, a rudimentary mapping may help shed some light. Sematech's working groups, noted above, are a potential model and starting point, as the **oral histories** of some participants suggest. This model may well be applicable to the NSTC, not least as a means of staying close to industry concerns and needs as well as a primary source of information.

NEW ARRANGEMENTS FOR HARMONIZATION

With respect to harmonization of U.S. chip export controls with those of allies and strategic partners, current modalities are inadequate. The Wassenaar Arrangement is a voluntary multilateral export control regime with 42 member countries that seeks to ensure international stability by promoting transparency and responsibility with respect to transfers of conventional weapons and dual-use products and technologies. Wassenaar was created in 1996 to succeed the Cold War-era Coordinating Committee for Multilateral Export Controls (COCOM), a more stringent control regime. Exports of some chip technologies to China by signatories are already restricted pursuant to Wassenaar commitments. However, any attempt to utilize Wassenaar to coordinate enhanced allied semiconductor export controls will necessarily be complicated, perhaps fatally, by the fact that Russia is a **Wassenaar member** and will likely oppose any tightening of chip export controls directed at China.

This reality suggests the need for new arrangements, perhaps informal but nonetheless effective, on the part of like-minded states. U.S. policymakers must understand that consultations and cooperation with allies and industry will be absolutely essential to the success of U.S. policy in this domain. That means close coordination on policy while genuinely taking into account partners' perspectives and needs. Clearly articulating specific objectives and consulting with industry on the effectiveness of proposed measures is more important than announcements of new "controls." The semiconductor space is not one for unrestrained unilateral action. Close cooperation, however challenging, is the path to success. ■

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This report is made possible by general support to CSIS. No direct sponsorship contributed to this report.