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The United States Cannot Take Leadership for Granted

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A Report of CSIS Renewing American Innovation

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Introduction

The U.S. semiconductor design industry is a critically important strategic asset. It enables technological leadership in defense systems and fosters competitive advantage in manufacturing industries such as computing, telecommunications, autonomous vehicles, and medical devices. Design accounts for over 50 percent of total value added in the production of semiconductors—more than any other activity associated with the production process.

U.S. designers are the global leaders in every major segment of the industry, not just among leading-edge fabless firms. It is unsurprising, then, that the CHIPS and Science Act of 2022—which was designed to respond to major shortcomings in the U.S. semiconductor ecosystem—does not devote much attention to design, focusing instead on chip manufacturing, manufacturing equipment, and packaging. However, reflecting its importance, the U.S. design industry faces a growing challenge from Chinese firms, which, backed with state support, are gaining global market share at the expense of U.S. designers. The recent release of the Chinese artificial intelligence DeepSeek app, which rattled Silicon Valley and financial markets, demonstrates the speed at which assumptions of U.S. technological leadership can be upended by China’s rapidly growing innovation capabilities.¹

In part, this reflects the impact of U.S. export controls. While these controls have disrupted the operations of Chinese chip design firms over the short run, their imposition has catalyzed an unprecedented state-backed effort to promote the self-sufficiency and international competitiveness of China’s design sector. This pushback by Chinese companies against Western sanctions has already produced startling achievements, most notably Huawei’s 2023 introduction of the Kirin 9000S

system-on-a-chip (SoC) manufactured on a 7 nanometer (nm) process for use in its Mate 60 Pro smartphone—a feat which, to the surprise of U.S. policymakers, occurred much sooner than anticipated.

Given the strategic and economic importance of maintaining U.S. chip design leadership along with China's determination to challenge it, U.S. policy deliberations over a possible "CHIPS Act 2.0" need to recognize the critical contributions of this industry. Ultimately, the United States will need to implement a range of policy measures to support continued U.S. leadership in design as well as in manufacturing.

Chip Design and National Security

The stakes are genuinely important. U.S. semiconductor design leadership means that U.S.-designed chips are superior to those from all other countries in terms of performance, sophistication, energy efficiency, and security—representing enormous strategic leverage. Moreover, because these chips are incorporated into virtually all U.S. defense platforms, the quality and reliability of the chips embedded in U.S. systems play a key role in battlefield performance, information acquisition, and evaluation.

The offshoring of U.S. chip manufacturing capability means that the most advanced U.S. designs are fabricated outside the United States, concentrated primarily on the island of Taiwan. This represents a significant strategic vulnerability for the United States, one that is at least beginning to be addressed.² Yet a much greater vulnerability would emerge if the United States' ability to create the most sophisticated and mission-specific chips were to be eclipsed by that of a strategic adversary.

Security: If an adversary could design and deploy chips more advanced than those in use by the United States, it could win a commanding advantage in every aspect of military preparedness, up to and including a major conflict. Should segments of the U.S. economy and defense industrial base ever find it necessary to utilize chips designed in China (or another adversarial state) because those chips were not available from domestic or friendly sources, then the United States' defense posture, cybersecurity, and counterintelligence operations could be compromised.

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Artificial Intelligence: Nowhere is the need for continued U.S. design leadership more apparent than in artificial intelligence, particularly with regard to the AI systems expected to determine both economic advantage and battlefield capabilities in the twenty-first century. Today, most leading-edge AI chips are designed by Nvidia, with other sophisticated U.S. design firms such as AMD making major advances. It is therefore no coincidence that recently tightened U.S. export controls have restricted not only the export of chip design software to "countries of concern" but also specific U.S.-designed chips with advanced AI applications.³ To counter these restrictions,

China is mounting well-funded efforts to improve its design capability for the chips needed to support AI.⁴ The 2025 release of the DeepSeek app is an indicator that these efforts represent a serious and multifaceted challenge—as one Chinese observer put it, “we should have confidence that China will eventually win the AI war with the US.”⁵

Cybersecurity: Chip design is also at the forefront of the ongoing struggle to ensure cybersecurity and to thwart hacking and tampering efforts, to which a number of “countries of concern” are reportedly devoting unprecedented resources.⁶ In a virtuous cycle, design leadership would improve the ability to protect design information and to trace and control design intellectual property (IP). Designing security into chips is becoming a multifaceted and complex challenge—as one engineer at one of the world’s leading fabless firms (Xilinx, which was subsequently acquired by AMD) observed:

We have to be able to encrypt the data coming in and encrypt the data going out. We may be able to reprogram your device and make sure that it’s coming from an authenticated source. And finally, we need to protect the IP that’s inside this device through cryptography and IP threat protection, with DPA (differential power analysis) resistance and things like that. All the security features that exist in our high-end devices need to be available in a low-cost FPGA [field programmable gate array].⁷

The Manufacturing Caveat: It is of course true that, at the leading edge of the chip industry, the sophistication of chip design must be paired with equivalently sophisticated manufacturing capability, capacity, and equipment, and as such, access to manufacturing capability and capacity must also be considered in assessing the security threat of an adversary’s chip design industry. China’s Huawei, for example, may design highly advanced chips, but its ability to manufacture such a chip at scale appears severely constrained, as China’s most advanced foundry, Semiconductor Manufacturing International Corporation (SMIC), is still generations behind the leading edge in both its processes and the equipment it deploys.

Despite this dynamic, Huawei and SMIC have proven to be a formidable partnership, reportedly stretching older-generation equipment to manufacture a chip at the 5 nm process, albeit with tremendous inefficiencies and at great cost.⁸ It is important to note that this is a capability that even the United States will lack until the various leading-edge CHIPS projects across the country begin high-volume production.⁹

Similarly, and perhaps most importantly, the design industry is far more diverse an ecosystem than just the leading edge. In many categories of semiconductors not defined by the density of their components, Chinese firms have the design talent, manufacturing capacity, scale, and resources to compete effectively with Western firms.

CHIPS Act Largely Aimed at Manufacturing

In February 2024, U.S. Secretary of Commerce Gina Raimondo spoke at CSIS to provide an update on the U.S. government’s implementation of the CHIPS and Science Act of 2022 (widely referred to as the “CHIPS Act”).¹⁰ This strongly bipartisan legislation was enacted primarily to address gaps and vulnerabilities in the country’s supply chain for semiconductors, most notably the absence of

manufacturing capacity on U.S. soil for the most advanced chips as well as limited manufacturing capability for “foundational” chips with applications in the automotive, telecommunications, defense electronics, and other manufacturing sectors essential to the U.S. economy. The CHIPS Act authorizes and appropriates \$39 billion in federal funding to encourage semiconductor manufacturing on U.S. soil, with an additional \$12 billion allocated for various research initiatives such as the National Semiconductor Technology Center (NSTC), National Advanced Packaging Manufacturing Program (NAPMP), and National Institute of Standards and Technology (NIST) metrology research.¹¹

In her address to CSIS, Secretary Raimondo underscored the advantages associated with the U.S. edge in chip design in the country’s overall competition with China in microelectronics. While the secretary was right to celebrate the strengths of the U.S. design industry, the existing CHIPS Act does not address the needs of U.S. chip designers in this increasingly competitive segment of the industry. The 400-page act is principally concerned with arresting the erosion of the domestic U.S. chip manufacturing base. To do so, it provides direct grants to support both foreign and domestic manufacturing firms in the United States. Although the act also includes a 25 percent tax credit for investments in chip manufacturing, a benefit estimated at \$46 billion by the Congressional Budget Office (but one that may considerably exceed that amount), it only indirectly addresses chip design.¹² U.S. chip design firms are not eligible for the direct federal funding authorized by the act or for the 25 percent tax credit; the federal funding is being directed toward manufacturers and their upstream equipment and materials suppliers only.

In fact, for chip design, there is only a relatively small and indirect amount of funding being allocated. NIST has released a vision for the NSTC that spells out, among many other initiatives, a plan for a “design enablement gateway” intended to “facilitate collaboration, reduce cost and time to market, and broaden access to important tools and information, all while respecting private companies’ IP.”¹³ The Department of Commerce CHIPS Office plans to allocate \$5 billion to support the NSTC, operated by the National Center for the Advancement of Semiconductor Technology (Natcast), as well as other R&D and workforce initiatives. The portion of this outlay that will be allocated to chip design is comparatively modest relative to the resources going to chip manufacturing.

This is not to question the wisdom of the CHIPS Act’s focus on manufacturing. The act was intended to address emerging and existing gaps and vulnerabilities in the U.S. chip supply chain that pose immediate risks to national security and future economic well-being. These immediate vulnerabilities are in the manufacturing and packaging of advanced chips. The design sector is not a “gap” or “vulnerability” in the U.S. chip supply chain—on the contrary, the United States is far and away the world leader in innovative ability, market share, and international competitiveness in this crucial sector. The sector is thus not an obvious candidate for public policy initiatives intended to mend holes in the U.S. industrial fabric.

However, viewed in a global competitive context and looking beyond the immediate challenges in chip manufacturing, the question of government support comes to the fore. As noted, design is the most valuable element in the entire chip production chain, and for that reason, China is supporting efforts by Chinese firms to challenge U.S. design leadership. The relative levels of public support combined with the absence of market discipline and growth in the Chinese talent base pose significant challenges to the U.S. industry’s ability to sustain its strong global position.

The Chip Design Landscape Today

Current U.S. Global Dominance in Design

While the U.S. semiconductor design industry is the strongest in the world, it is important to recognize that it is heterogeneous, consisting of five main types of companies. In each of these subsectors, U.S. firms enjoy a strong global competitive position, at least for now. According to a 2022 study by the Semiconductor Industry Association and the Boston Consulting Group (henceforth the “SIA/BCG study”), 50.2 percent of global semiconductor revenues in 2023 were derived from the design activities of U.S.-based firms—2.5 times as much as from any other region.¹⁴ With respect to logic devices, U.S.-based design activities accounted for 65 percent of global revenues in 2022.¹⁵ These revenues, and companies’ willingness to draw from them to invest massively in R&D, are essential to maintaining the U.S. lead across a range of technologies.

Integrated Device Manufacturers (IDMs): IDMs are vertically integrated entities that both design and manufacture semiconductors. Major U.S.-based IDMs include Intel Corporation, Micron Technology, and Texas Instruments. Intel is currently forecasting that its design effort will progress dramatically—by five chip nodes in four years—entering what it calls the “Angstrom Era.” While currently facing some turbulence, Intel’s stated goal is to incorporate 1 trillion transistors in a single processor package by 2030, about 10 times the current number.¹⁶

Fabless Firms: Fabless firms focus exclusively on semiconductor design, outsourcing the production of chips based on their designs to foundries that specialize in manufacturing, thereby avoiding the enormous capital costs associated with the most advanced manufacturing. This enables these firms to concentrate on chip design—and, more importantly, to concentrate their

substantial R&D expenditures only on chip design. By comparison, IDMs must invest major sums in both design R&D and the capital outlays needed to build the fabs and the assembly, test, and packaging facilities that fabricate the chips they design.

The economic advantages of being fabless are compelling. Seven of the world's top ten fabless firms by revenue are U.S. companies, including Nvidia, Qualcomm, and AMD.¹⁷ In addition, five of the world's top ten global firms in 2023 by annual revenue were fabless firms. Finally, from a U.S. semiconductor industry point of view, five of the U.S. industry's top six companies by annual revenue in 2023 were fabless firms. The U.S. semiconductor industry has largely embraced the fabless business model and its avoidance of the heavy capital costs of production. The United States is the current global fabless leader, an important factor underlying the U.S. industry's global leadership in chip design.

Importantly, U.S. strengths in design now underpin the growth in AI. Artificial intelligence chips designed by Nvidia account for over 80 percent of the market for advanced AI chips and “underpin all of the most advanced AI systems.”¹⁸ Nvidia is one of the United States' five most valuable firms, with a market valuation of over \$3 trillion as of July 2024.¹⁹ A central goal of the CHIPS Act was to ensure that at least some of these advanced chips could be manufactured in fabs within U.S. borders.

Original Equipment Manufacturers (OEMs): OEMs use semiconductors in other products they make, such as smartphones and automobiles. In recent years, OEMs have begun designing advanced chips tailored for use in their own end products, and U.S.-based OEMs have enjoyed dramatic successes designing custom chips. Apple, for example, designed its own “Apple silicon” series processors, first for its smartphones and tablets, then replacing Intel-designed and fabricated chips for its PCs in 2020—reaping “huge benefits,” particularly via increased PC market share.²⁰ Other major U.S. OEM chip designers include Amazon and Microsoft.

Electronic Design Automation (EDA) Firms: EDA firms provide automated design tools and many types of services to chip designers. While not chip designers themselves, their software is indispensable for the design of advanced semiconductor devices. The world's three leading EDA software firms—Synopsys, Cadence Design Systems, and Mentor Graphics—are located in the United States; Mentor Graphics is owned by the German firm Siemens but operates in the United States.²¹

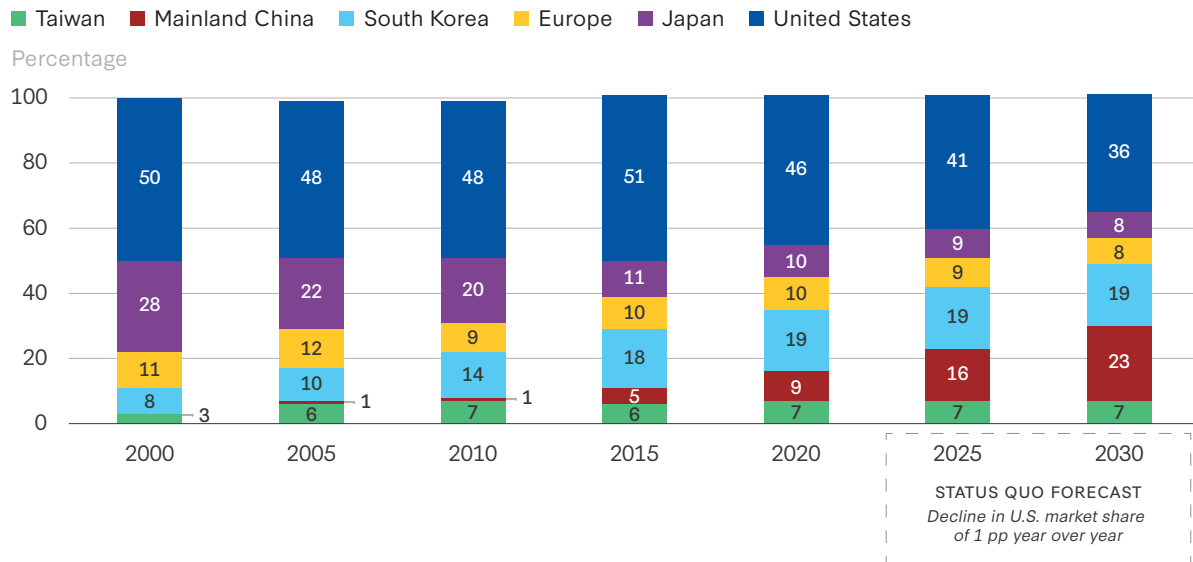
Intellectual Property (IP) Providers: IP providers license intellectual property that can be used as building blocks for new designs, avoiding the cost and added time of developing an entirely new design from scratch.²² Many firms license IP as a source of revenue, but in 2021, U.S.-based firms accounted for the largest share (72 percent) of revenues from EDA and IP blocks, with Europe accounting for most of the rest (20 percent). The leading European firm in this space is UK-based Arm Holdings, which licenses processor cores to design companies. As of 2020, Arm cores drove 90 percent of mobile phone applications worldwide and 34 percent of the entire semiconductor industry.²³

Clouds on the Horizon?

Given the dominant position of the U.S. chip design industry, one could fairly ask: What is the problem? Recent projections of an eroding global market share have not materialized. The 2022

SIA/BCG study, which warned that U.S. market share fell from 50 percent in 2000 to 46 percent in 2020, forecast that it would fall further to 36 percent by 2030, reflecting the emergence of the Chinese chip design industry (which accounted for almost zero percent of the global market in 2000, rose to 9 percent in 2020, and was forecast to hit 23 percent in 2030).²⁴ To be sure, the most recent data available, from 2023, shows the U.S. share recovering to 50.2 percent by 2030, reflecting recent market successes of U.S.-designed AI- drive server chips. However, the advent of China’s DeepSeek AI app, developed despite U.S. export controls on AI chip technology, suggests that the 50.2 percent figure may be overly sanguine.

Figure 1: Projected Erosion in U.S. Market Share of Global Semiconductor Design



Source: Ramiro Palma et al., “The Growing Challenge of Semiconductor Design Leadership,” Boston Consulting Group and Semiconductor Industry Association, November 2022, 13, <https://web-assets.bcg.com/3f/b4/fd384ccd46dc8a381bd61a648105/bcg-the-growing-challenge-of-semiconductor-design-leadership-nov-2022-r.pdf>.

Importantly, figures depicting only total global market shares mask trends in submarkets that concern industry observers. The gross numbers in the SIA/BCG study and in more recent surveys do not reflect the fact that U.S. chip design firms are not the market leaders in every semiconductor design product subsegment, nor do they show that in some areas, U.S. designers face growing challenges from China. According to the SIA/BCG study, in 2021, U.S. firms held an overwhelming share of submarkets for advanced processors (88 percent) and analog devices (58 percent) and maintained the leading share in other logic devices (31 percent, versus 28 percent for Europe). Still, in other important categories U.S. firms trail the market leaders:

Optoelectronics: In 2021, U.S. design firms accounted for only 13 percent of the optoelectronics market, versus 35 percent for Japan, 15 percent for China, and 15 percent for Korea. In 2023, the Chinese Academy of Engineering designated optoelectronic semiconductors as one of 14 “challenges it wants to crack.”²⁵

Memory: In 2021, U.S. firms accounted for 28 percent of the memory market versus 57 percent for Korea. But in late 2023, China's leading DRAM developer, ChangXin Memory Technologies (CXMT), unveiled a concept design featuring gate-all-around (GAA) transistor architecture, which is equivalent to global state-of-the-art memory designs.²⁶ This shows significant Chinese progress in design, although CXMT's timeline and capacity for manufacturing such a chip remain unclear.

Non-Optical Sensors: In 2021, U.S. firms held an 18 percent share of the market for non-optical sensors, versus 31 percent for Europe and 22 percent for Japan.²⁷ China's 2021 *Three-Year Action Plan for the Internet of Things* calls for targeted support for temperature, gas, motion, photoelectric, velocity, and biochemical sensors (e.g., non-optical sensors).²⁸

Discrete Devices: Discrete devices are chips with only one transistor.²⁹ Although not technologically sophisticated, these have ubiquitous applications and represent a supply chain risk if not available in adequate quantities to U.S. manufacturers. In 2021, U.S. firms held a 27 percent share of the market for discrete devices, versus 36 percent for Europe and 26 percent for Japan. According to one source, China attained self-sufficiency in discrete chips in 2013.³⁰

The Next Generation of Design Engineers: Even in EDA tools, where U.S. firms hold an apparently insurmountable edge over China, Chinese observers see a long-range opportunity for their country. One commented in 2019 that “if you look at the main [U.S.] companies in this software market segment, the average age of many [of their EDA engineers] is like 50 years old now. So, this is an opportunity for China to invest [in talent and other resources to support EDA research and development],” especially since academic researchers in the United States are not getting enough funding to pursue further EDA development. “So, these professors and a lot of engineers have moved on to do something else.”³¹

The Need for a Long-Term, Well-Financed Effort on Talent

The above comment highlights the importance of a long-term view of a nation's talent base and support for the research that will underpin future private investments. The U.S. Chips for America Strategy, which outlines the planned implementation of the U.S. CHIPS Act, acknowledges that at present, “there is a severe shortage of workers who are trained and ready to fill new roles in specialized construction, fab operations, and semiconductor design,” and forecasts that as much as \$8 billion will be required to expand the existing worker base.³² In chip design, initiatives are needed to scale up the existing workforce and create pathways through community colleges and four-year institutions to feed students into the design pipeline.

Given that China is and will remain the United States' principal strategic competitor, a key question for U.S. policymakers is whether the recent strides of China's chip design sector represent a competitive and strategic challenge to the United States. Clearly, they do. A 2023 study by the European research consortium Digital Power China posed the same question from a European perspective and concluded that:

The growing competitiveness of Chinese chip design companies has so far been neglected by policymakers in Europe. Despite the recent U.S. export controls targeting China's semiconductor industry, it is highly likely that Chinese chip design companies will gain global market share in a range of industry sectors in this decade. This presents challenges across the dimensions of national security, supply chain resilience, and technological competitiveness for Europe, its end-customer industries and semiconductor companies. Importantly, most of these challenges are not addressed by the proposed European Chips Act and will require different and tailored policy responses.³³

Arguably, the same could be said of the U.S. CHIPS Act. The challenges the report describes in security and competitiveness for Europe are clearly the United States' challenges as well. To address them, U.S. policymakers need to break away from the constraints of outmoded views on global trade and industrial policy and instead address the reality and effectiveness of the state-backed enterprises focused on challenging the U.S. design industry. Tailored measures to support U.S. design firms are necessary in the face of this unprecedented Chinese national effort to displace them. Both serious resources and adaptive policies will be required.

China's Advances in Chip Design

China's share of the global chip design market grew from virtually zero in 2003 to 7 percent in 2023. While these growth figures are impressive for a new entrant, they do not suggest a serious threat to U.S. global leadership in the near term. However, one must recognize the long-term challenge represented by the Chinese government's determination to transform the country's design sector into a global competitive leader and a pillar of China's national defense posture, as well as the magnitude of government resources being committed to that effort. Although China's chip designers have been set back by Western sanctions, it is likely that sustained governmental support at scale and the growing quality of Chinese research and engineers complemented by the large domestic market will enable the nation's design sector to continue to expand its global market share.

Massive Government Support

In global competition for high-tech industry, there is arguably no parallel for the sheer scale of China's commitment of public resources to the semiconductor industry. In 2014, the State Council released the *National Guideline for the Development and Promotion of the Integrated Circuit Industry* ("National IC Plan"), setting forth a long-range plan to promote the domestic semiconductor industry.³⁴ Concurrently, it established the China Integrated Circuit Industry Investment Fund (also known as "the Big Fund") to undertake investments in the semiconductor industry, combining government, private, and public-private funds.³⁵ Wenwu Ding, the president of the Big Fund, said that the plan was to make \$100 billion dollars available to the semiconductor ecosystem from central, regional, and local governments and public/private investment vehicles.³⁶

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These measures were followed in 2015 by the State Council's release of *Made in China 2025*, a ten-year plan for promoting national manufacturing industries—particularly “core development sectors” such as semiconductors, which were to be promoted for “breakthrough development.” At the end of 2022, China was reportedly planning to spend an astonishing \$143 billion over the next five years to promote the domestic semiconductor industry.³⁷

The Chinese National IC Plan emphasizes the importance of semiconductor design. A 2024 joint study by the Semiconductor Industry Association and the Boston Consulting Group found that in the first two rounds of funding from the Big Fund, Chinese fabless design companies received billions of dollars in public funding.³⁸ In 2024, the Chinese government announced a third phase of the Big Fund, with registered capital of \$47.5 billion.³⁹

It is difficult to calculate with precision the total amount of Chinese government funding directed to chip design; in addition to fabless firms, the first two rounds of investment from the Big Fund directed over \$10 billion to IDMs, which included but was not limited to design activities.⁴⁰ These firms, which include Huawei, Tencent, Xiaomi, and Alibaba, have developed robust internal chip design capabilities—usually through subsidiaries—that have surprised Western analysts.⁴¹ In addition, regional and municipal governments, particularly those of Shanghai and Shenzhen, have provided strong direct support to China's chip design firms.

Reflecting the government's support for the chip design industry, venture capital has poured into the design sector. In 2020, 67.2 percent of venture capital investments in the Chinese semiconductor industry were in IC design.⁴² In addition, China exempts key design firms from corporate income tax for five years after their first profitable year and taxes at a reduced rate of 10 percent thereafter.⁴³

The government's demonstration of support for the semiconductor design sector has fostered a “gold rush” of start-ups in the design space, in which barriers to entry are relatively low, particularly when compared to manufacturing. According to one report, as of September 2020 there was an astounding total of 138,000 semiconductor design start-ups in China, most of them registered after the formation of the Big Fund in 2014.⁴⁴

Taken on its own, a vast landscape of firms responding to abundant funding does not indicate success. Huge numbers of these firms have failed and will continue to fail. In the summer of 2024, for instance, the promising start-up X-Epic, a developer of indigenous EDA software, reportedly slashed its 400-person workforce by half, “casting a shadow over Beijing's efforts to achieve tech self-sufficiency,” in one observer's view.⁴⁵ X-Epic's predicament is representative of the broader asphyxiation of China's start-up ecosystem since the pandemic. According to the *Financial Times*, China's start-up launches in 2024 totaled just 260, down from a peak of over 50,000 in 2018. “The whole industry has just died before our eyes,” one Chinese executive lamented.⁴⁶

Despite the downturn, there has been some success with a few key players emerging, including Loongson Technology, a designer of general-purpose microprocessors; Black Sesame, a designer of low-power automotive chips; Biren Technologies, a designer of general-purpose GPUs; and Horizon Robotics, a designer of autonomous driving computing chips. Nor has the ecosystem died. At present, there are over 3,000 fabless design firms in China, collectively with double-digit annual growth.⁴⁷

The Impact of Western Export Controls

Recognizing the growing geopolitical threat posed by China's increased capabilities in this industry, the United States and some allies began curtailing the export of semiconductor technology to China in 2019, when the Trump administration placed Huawei and 68 of its non-U.S. affiliates on the Entity List—effectively barring them from using U.S. chip technology and software, including all U.S. EDA tools, when their licenses expired.⁴⁸ At the time it was believed that “without American EDA tools, it would be basically impossible for Huawei to design chips.”⁴⁹ Since then, the Biden administration has further tightened controls on exports of U.S. chips, chip technology, and chip design and manufacturing tools. In 2022, it announced multilateral controls on the export of certain EDA tools that can be used to design gate-all-around field effect transistor (GAAFET) architecture, currently the most advanced.⁵⁰

Western sanctions dealt a serious blow to China's chip designers, which could, until 2022, rely on U.S. EDA design tools and IP. Reflecting the apparent ease of accessing foreign technology, relatively little had been done to develop domestic EDA capability or ownership of IP: “So long as indigenous firms could tap the best of what the world had to offer, local investors had low economic incentives to reinvent the wheel.”⁵¹

In addition to losing access to the most advanced chip design tools, Chinese chip designers experienced diminished access to foreign foundries, particularly TSMC, which had formerly fabricated their most advanced designs. By curtailing its services for Chinese designers in response to Western export controls, TSMC dealt a blow to HiSilicon, Huawei's design subsidiary, and Zeku, the chip design subsidiary of Chinese smartphone maker Oppo, causing Zeku to shut its doors.⁵² Two top Chinese designers of AI chips, MetaX and Enflame, have reportedly submitted downgraded versions of their designs to TSMC to comply with U.S. restrictions. The two firms had previously marketed their chips as being comparable to Nvidia's graphics processing units (GPUs).⁵³

Still, the Chinese government and chip industry have demonstrated considerable resilience and ingenuity in response to Western sanctions. Although the sanctions have indisputably disrupted China's semiconductor industry in the near term, the response has been to implement countermeasures which, over the long term, will substantially enhance the competitiveness of the Chinese chip industry and reduce its dependency on foreign technology.

Sanctions are thus having the concerning longer-term effect of incentivizing China to create its own indigenous design tools and encouraging unprecedented support for the industry. In a sense, the sanctions have highlighted the structural advantage of Chinese firms. They do not have to have better technology, much less be profitable; they only have to capture market share, allowing

them to move down the cost curve and up the learning curve while reducing Western competitors' revenue—and therefore their resources to invest in the next generations of technology.

Huawei's Central Role

China's dominant telecommunications equipment maker, Huawei, is also the country's largest consumer of semiconductors and its leading chip designer, primarily through its design subsidiary, HiSilicon. According to a widely cited Bloomberg report, the U.S. blacklisting of Huawei in 2019 induced the Chinese government to turn to the company as “the effective captain of China's effort to develop a self-sufficient chip industry . . . In Huawei they have a rare national champion with the grit, scale and technological prowess to push back.”⁵⁴

Huawei overhauled its operations to redesign its equipment and software so they could function without U.S. technology. Huawei's current-generation smartphone, the Pura 70 line, incorporates 33 China-sourced components and only 5 sourced from outside China.⁵⁵ At the same time, Huawei began to provide engineering expertise and financial support to smaller companies in key parts of the semiconductor supply chain.⁵⁶ HiSilicon, the largest chip design company in China, is best known for its development of all the chips for Huawei's smartphones and tablets, most notably the Kirin range. One of its recent chips was recently shown to outperform Nvidia's flagship V100 device in some respects.⁵⁷

In addition to Huawei's efforts, a number of China's big data equipment manufacturers are stepping up their efforts to promote advances in domestic chip design, including Baidu, Tencent, Xiaomi, and Alibaba. These firms bring substantial resources and proven track records and may well offer a path to a more robust domestic industry.

The Challenge of Indigenous EDA Tools

As of 2023, EDA tool firms Cadence, Synopsys, and Siemens EDA controlled 80 percent of China's market. U.S. export controls have compelled these firms to curtail some China sales—including, significantly, EDA software containing GAAFET technology, which is needed to support the design of AI chips.⁵⁸ Although China has little to no prospect of developing its own advanced EDA tools in the near future, U.S. leadership should not be taken for granted over the longer term.

From Policy Neglect to Focus

EDA was neglected by Chinese government policymakers until the advent of sanctions. As one industry observer noted: “For the longest time, Chinese industrial policymakers didn't realize [EDA software] is the real bottleneck.”⁵⁹ Somewhat belatedly, China's current Five-Year Plan now lists EDA as the “first cutting-edge technology in the semiconductor industry where China needs to make breakthroughs.” Reflecting this change in orientation, domestic EDA developers are receiving substantially increased government financial support and have made some early gains.⁶⁰ For example:

- In 2022, the municipal government of Shanghai said it would subsidize 30 percent of the cost of chip software investments such as EDA tools.⁶¹

- The same year, the municipal government of Shenzhen committed to providing a subsidy of up to \$1.4 million to companies that buy “home-grown” EDA tools.⁶²
- A number of executives from U.S. EDA firms have left to join Chinese rivals “as Beijing seeks to break America’s near monopoly on this key segment of the semiconductor industry.”⁶³
- China’s leading EDA developer, Empyrean Technology, experienced a sixfold increase in revenues between 2018 and 2023.⁶⁴
- In April 2024, the Chinese firm Xinhuaazhang introduced its first EDA design software that can work on domestically made processors (Huawei’s Kunpeng processors and Phytium’s Feiteng devices). As observed by one industry expert, “this is a significant development for China’s semiconductor industry as domestic chip designers can now design devices and simulate them using solely domestic software and hardware.”⁶⁵

Relevantly for the long-term effectiveness of Western sanctions, EDA tools are software, which are more difficult for Western allies to control than hardware like lithography equipment. A recent article in the MIT Technology Review notes that “EDA software tools are distributed online, so they can be pirated. Chinese companies could either hold onto the EDA software they have already purchased or resort to hacking licenses or acquiring them through shadow entities.”⁶⁶

Chinese firms are seeking to acquire Western companies with EDA competencies—in 2022, the United Kingdom rejected a bid by a Shanghai software developer to take over Pulsic Limited, a developer of chip design software.⁶⁷ One analyst suggests that Chinese design firms can continue to acquire EDA tools by setting up shell companies with no apparent connection to firms on the Entity List as a legal front for acquiring EDA licenses, perhaps in collaboration with foreign EDA vendors.⁶⁸ And in April 2022, the U.S. EDA supplier Synopsys was reportedly under investigation by the Department of Commerce for allegedly sharing its design software with HiSilicon.⁶⁹

The RISC-V Challenge

The Chinese government is encouraging domestic chip designers to utilize RISC-V reduced instruction set architecture for custom processors as an alternative to licensing IP blocks from Western firms such as Intel and Arm. RISC-V is an open-source architecture managed by a Swiss foundation that allows semiconductor design teams to access and implement RISC-V standard free of charge.⁷⁰ It is not subject to U.S. and allied export controls, and Chinese entities including Alibaba, Huawei, ZTE, and Tencent are active participants in the RISC-V foundation.⁷¹ Members of the U.S. Congress recently warned that China might use RISC-V to circumvent U.S. export controls on general computing processors, should the United States decide to adopt them in the future.⁷² In April 2024, the Department of Commerce said that it was reviewing the national security implications of China’s use of RISC-V technology.⁷³

The Beijing Open-Source Chip Research Institute, a group of research centers that includes the Chinese Academy of Sciences and hyper-scalers Tencent and Alibaba, is developing indigenous chip design architecture based on RISC-V. According to the *Silicon Triangle* report, “if it succeeds, the

group's Xiangshan RISC-V architecture could free China from IP constraints imposed by Arm, the Cambridge-based company whose technology underlies most cell phones, including Apple products.”⁷⁴

Government incentives are being offered to spur adoption of IP that implements RISC-V in chip designs, and domestic design firms are reporting successes in applying RISC-V architecture. The municipal government of Shanghai was the first to kickstart RISC-V development in 2018, offering specific financial incentives to encourage companies to develop RISC-V processors and related IP. In that year, the city oversaw the formation of the RISC-V Industry Alliance, convening local start-ups in a collaboration that had grown to 173 companies by mid-2023. In 2023, nine leading chip design firms, including Alibaba's chip unit T-Head and Baidu-backed StarFive, formed a patent alliance for RISC-V to enable IP sharing and third-party licensing to promote a “healthy” open-source environment and the “rapid development of RISC-V technologies.”⁷⁵ The municipal government of Shenzhen is providing up to \$1.4 million to firms that are working on open standard RISC-V chip design architecture.⁷⁶

These efforts are bearing fruit, with Chinese chip designers reporting successes in applications of RISC-V architecture:

- In December 2022, a dozen Chinese chip firms launched 11 new RISC-V-based chips with applications in wireless communications, automobiles, security, and energy management.⁷⁷
- In 2023, Alibaba's chip design subsidiary, T-Head, launched a RISC-V-based controller chip, Zhenyue 510, for applications in artificial intelligence training, online transactions, and big data analysis.⁷⁸ A T-Head executive said that his company was launching an initiative to encourage 150,000 developers to learn about and secure international credentials with respect to RISC-V.⁷⁹
- Alibaba's research arm, Damo Academy, announced in 2024 that it expects to launch the next generation of its RISC-V XuanTie processors, the C930, in 2024. The new chip has applications in 5G communications, robotics, and financial services.⁸⁰

Upgrading Domestic Foundries for Independence from the Global Network

Interestingly, to reduce its dependence on foreign firms, China is now devoting massive government resources to upgrading its domestic chip foundries—an effort which, if successful, would partially mitigate indigenous designers' loss of access to TSMC and other Western foundries with respect to the production of high-end designs. Domestic foundries such as SMIC and Hua Hong Semiconductor are reportedly “actively” increasing capacity, particularly for the production of legacy chips used in current industrial applications. Total Chinese foundry capacity is forecast to grow by 15 percent in 2024 alone.⁸¹

Western sanctions prevent Chinese foundries from utilizing ASML's most advanced lithography equipment, based on extreme ultraviolet (EUV) technology, which is needed to make the 2, 3, and 5 nm chips supporting advanced artificial intelligence. An open question is how far Chinese foundries can push their existing chipmaking capabilities to close the gap with Western chip firms. Huawei “shocked the world” in 2023 by unveiling its 7 nm processor in collaboration with the domestic foundry SMIC.⁸² As noted earlier, Huawei is reportedly set to launch a smartphone with an SoC

manufactured with SMIC's 5 nm process in October 2024.⁸³ Whether these chips can be produced cost effectively at scale remains to be seen from a commercial perspective, but it does suggest they might be able to produce chips to meet high-end defense requirements.

Recent Chinese Chip Design Achievements

Although the Chinese chip design sector has been shaken by Western export controls, it is rapidly developing workarounds. An executive at a Chinese EDA firm said in December 2024 that while China “is blocked from advanced processing technologies, both in software and hardware . . . using 3D stacking and heterogenous integration offers a long-term viable solution to bypass sanctions.”⁸⁴ The implementation of U.S. export controls has been paralleled by significant Chinese advances in chip design, calling into question the long-term effectiveness of U.S. restrictions.

October 2022: The U.S. Bureau of Industry and Security (BIS) releases initial export controls on advanced chip technology and manufacturing equipment to China.

November 2022: Moore Threads Technology, a U.S.-blacklisted Chinese GPU design firm founded by a former Nvidia executive, is proving adept at quickly developing alternatives to foreign-restricted chips with consumer electronics applications. The company's MTT S80, introduced in 2022, is being compared favorably by video gamers with Nvidia hardware. Although the MTT S80 does not perform as well as Nvidia's GeForce RTX 3060, it costs about 40 percent less, opening opportunities to capture significant market share and the associated revenues to fund further development.⁸⁵

April 2023: Tencent announces that despite Western sanctions it is entering mass production of a chip developed in-house, a video transcoding processor called Canghai that will be used to power cloud gaming and video streaming.⁸⁶

October 2023: BIS releases updated controls to close loopholes, expand sanctioned firms, and control additional categories of equipment.⁸⁷

December 2023: HiSilicon designs the Kirin 9000s, the 7 nm SoC that supports Huawei's Mate 60 Pro smartphone—a development that startles U.S. officials concerned about the effectiveness of U.S. and allied chip export controls.⁸⁸

December 2023: ChangXin Memory Technologies (CXMT) presents a paper at the IEEE International Electron Devices Meeting indicating “its design capabilities for gate-all-around (GAA) transistors—the most advanced transistor type for cutting-edge 3-nanometre grade chips.” CXMT's presentation “grabbed the attention of industry analysts, as the design of such chips typically involves technologies that are subject to US export restrictions.”⁸⁹

July 2024: Huawei is reportedly considering incorporation of 5 nm chips designed by SMIC despite U.S. sanctions in upcoming versions of its Mate 70 smartphones.⁹⁰

September 2024: ByteDance, the owner of TikTok, is reportedly planning to use TSMC to manufacture two of its 5 nm chip designs to reduce dependency on Nvidia chips. ByteDance denies these reports, stating that all of its chip projects are “in compliance with relevant trade control regulations.”⁹¹

October 2024: SenseTime group, a partially government-owned Chinese AI software firm, discloses that it was using “a lot” of domestically produced chips “to train its large language models as part of its efforts to rapidly develop a homegrown AI computing ecosystem.” The company noted, in particular, Huawei’s latest AI accelerator, Ascend910C, which it said offers “a significant performance improvement.”⁹²

November 2024: TSMC reportedly tells multiple Chinese customers that it was suspending production of their AI and high-performance computing chips in order to ensure compliance with U.S. export controls.⁹³ Similarly, Xiaomi is reportedly “preparing a self-designed mobile processor for its upcoming smartphones in an effort to reduce its reliance on foreign suppliers Qualcomm and MediaTek.”⁹⁴

December 2025: The Biden administration expands its blacklist of Chinese chip firms, extending it to Chinese suppliers of EDA software, semiconductor manufacturing equipment, specialty gases, and infrastructure firms supporting Huawei’s chip development efforts.⁹⁵

January 2025: The United States tightens its controls on exports of semiconductors to China, restricting all exports of chips under or at 14 and 16 nm, with transistor counts exceeding 30 billion.⁹⁶

January 2025: China’s leading designer of memory chips, YMTC, has reportedly “achieved a significant technological breakthrough despite US sanctions,” a “dual deck” memory device joining two wafers together through hybrid bonding to produce a total of 294 gates. Memory chip leaders like Samsung and Hynix are reportedly watching these developments with the concern that YMTC’s hybrid bonding technology may enable stacking of additional layers.

Potential Chinese Workarounds to Sanctions

Chinese policymakers and industry executives are exploring innovative ways to work around Western sanctions, efforts which likely would not have been undertaken absent the restrictions.⁹⁷ While at first glance some of these solutions appear far-fetched, it is not inconceivable that they could lead to destabilizing breakthroughs—an excellent example of which is the January 2025 release of the DeepSeek AI app.

Packaging: A stratagem reportedly being used by Chinese chip designers to offset the impact of sanctions is engaging Malaysian packaging firms to assemble GPUs to support AI, a move that apparently does not violate the sanctions. As noted in Malaysian news sources, “advanced packaging of chips can significantly improve chip performance and is emerging as a critical technology in the semiconductor industry,” enabling, among other things, the creation of “chiplets where chips are packaged tightly to work as one powerful brain.”⁹⁸ While China lags behind Taiwanese, Korean, and U.S. firms in advanced packaging technology, it still promises to stretch the performance of domestically designed and manufactured chips.⁹⁹

Photonics: Chinese scientists have reportedly developed a low-cost method for producing photonic integrated circuits for use in supercomputers and data centers using photons to communicate information, based on the material lithium tantalate. The discovery is expected to help “reduce the impact of US sanctions.”¹⁰⁰ In October 2024, China’s silicon photonics JFS Laboratory disclosed that it had succeeded in lighting up a laser light source integrated with a silicon-based chip, filling in “one of the few blanks” in China’s optoelectronics technology.”¹⁰¹ Chinese scientists are also reportedly experimenting with alternatives to silicon substrates to circumvent sanctions, such as silicon carbide, cubic boron arsenide, and graphene.¹⁰²

Alternative Forms of Lithography: China’s Tsinghua University has announced a plan to bypass Western restrictions on the export of lithography machines by developing a particle accelerator with an electron beam that can serve as a high-quality light source for on-site chip manufacturing. The plan is to build a “colossal” factory housing multiple lithography machines arrayed around the particle accelerator, enabling production of 2 nm chips in high volume.¹⁰³

Long-Run Prospects: China’s Inherent Advantages

While Western sanctions have dealt a severe blow to China’s semiconductor design ecosystem, they have also served as a major stimulus to the indigenous development China has sought for decades. And it is important to keep in mind that over the long term, China’s design sector enjoys intrinsic advantages that will ensure that its global market share grows throughout the remainder of this decade and beyond. The massive and focused government support noted above is assured, providing major incentives in resources and reliable ongoing support for firms to invest—a situation in sharp contrast to that endured by early-stage Western firms. China also benefits from other positive factors, such as the following:

Massive Domestic Demand: China consumes over half of the world’s semiconductors, and demand from domestic OEMs represents an enormous potential advantage for Chinese chip designers. Chinese OEMs account for 27 percent of global chip demand.¹⁰⁴

New Domestic Alternatives: As noted, traditionally China-based OEMs have depended heavily on imported chips, but “as a direct result of US export restrictions, non-US OEMs are increasingly turning to locally designed semiconductors.”¹⁰⁵ The geographic proximity of Chinese designers to domestic OEMs represents an added advantage. Restrictions on the sale of advanced Nvidia AI chips, for example, induced local OEMs to turn to Huawei-designed Ascend chipsets as an alternative; an executive at a major Chinese internet company said that the performance of the Huawei chipsets “was inferior to Nvidia chips, but we can definitely use them.”¹⁰⁶ Over the longer term, Chinese strengths in 5G, Internet of Things, electric vehicles, and other end-use markets will increase demand pull for Chinese chip designs.¹⁰⁷

Human Capital: In 2020, China graduated 2 million people with bachelor’s degrees in science and engineering, more than double the United States’ 900,000.¹⁰⁸ While the quality of these graduates may vary, semiconductor design is unusually reliant on creative individuals, and over the long

run China's ability to educate vast numbers of students with the requisite skill sets constitutes an enormous competitive asset.

In 2018, China launched the 2029 STEM Action Plan to promote students' access to STEM education, and in 2019, China added STEM to its primary school curriculum. Concurrently, the Ministry of Education created IC doctoral programs at 19 universities.¹⁰⁹ Significantly, a European study observed in 2023 that for the first time, at the 2023 International Solid State Circuits Conference—a highly prestigious academic semiconductor conference—a majority of the accepted papers were submitted by Chinese institutions.¹¹⁰ At the same time, the 2022 SIA/BCG study of the U.S. design sector warned that “the supply of [U.S.] design talent is dwindling” and forecast a shortfall of 23,000 designers by 2030, reflecting “the number of experienced engineers leaving the industry” and the inadequate number of U.S. STEM graduates.¹¹¹ This situation is compounded by current restrictions on immigration limiting access to high-quality engineers eager to work in the United States.

Conclusion

The Need for Policy Continuity and Resources at Scale

In February 2024, Secretary Raimondo called for CHIPS-related follow-on legislation supporting additional investments in semiconductors: “Whether you call it Chips Two or something else—continued investment [is needed] if we want to lead the world.”¹¹² Gaurav Gupta, an executive at the Gartner consultancy, strongly concurs:

This is the first time this money has been made available. And, as a result, you’re seeing a lot of chipmakers announcing new fabs and capacity expansions . . . But this has to be a more consistent policy from the US government through the next decade and beyond if they’re really serious about bringing back more chip manufacturing here in the US.¹¹³

To realize the new Trump administration’s goal of sustaining U.S. technology leadership in semiconductors, doubling down on support, backed by substantial and sustained investments and incentives, is essential. For this effort to succeed, U.S. policymakers need to recognize the strategic importance of the chip design sector and the unprecedented challenges it faces. Chip design is the highest value additive stage of semiconductor fabrication, accounting for over 50 percent of the value of a semiconductor, more than even front-end fabrication. Design leadership represents a huge economic and strategic advantage for the U.S. economy. As such, it is by far too valuable a competitive advantage to lose, and public policy deliberations to secure the future of the U.S. semiconductor industry must be broadened accordingly to assure continued leadership in semiconductor design. The industry’s current success is no guarantee of its future.

To realize the new Trump administration's goal of sustaining U.S. technology leadership in semiconductors, doubling down on support, backed by substantial and sustained investments and incentives, is essential. For this effort to succeed, U.S. policymakers need to recognize the strategic importance of the chip design sector and the unprecedented challenges it faces.

What Policies Are Needed?

The incoming Trump administration has recognized the strategic challenges facing the U.S. semiconductor industry. While the exact policy measures needed to ensure the continued success of U.S. chip design remain to be determined, the 2022 SIA/BCG study offered valuable suggestions for policymakers' consideration.

1. **Increase Investment:** Increased public investments and tax incentives to support chip design R&D are needed, particularly as the doubling of precompetitive chip R&D from 2023 to 2027 authorized in the CHIPS Act has not been appropriated. Given Chinese government focus, subsidies, and investments in research and talent, these funds need to be made available to U.S. labs and universities. Investment resources are essential for the United States' long-term ability to compete, a perspective China fully understands and is reflected in the scale of its R&D and educational investments.
2. **Promote Domestic Talent:** As in the space race, financial incentives are needed to increase the number of students entering STEM fields and to encourage undergraduates and graduate students to enter the field of chip design.
3. **Grow the Talent Pool:** There should be a targeted, national security-based reform of immigration policies to enable well-trained foreign chip designers to enter and remain in the United States. Given the challenge, the United States needs policies comparable to those put in place to attract international physicists for the Manhattan nuclear program.
4. **Recognize the Calming Value of Trade:** U.S. chip design leadership would be aided by adopting trade and export control policies that do not accelerate the balkanization of global markets and that reduce incentives for autarkic policy approaches. Despite intensifying competition and the need for policy measures to address the challenges posed by Chinese mercantilism, the global economy remains tightly linked. Greater disruption in this sector could be costly and may well be counterproductive.
5. **Expand Tax Incentives:** It is worth noting that an investment tax credit of 25 percent for chip design was nearly included in the CHIPS Act, a proposed measure that would be essential to include in the next round of legislation.

These and other measures should be part of ongoing policy dialogue to identify industry needs and policies to ensure continued U.S. leadership in this strategic segment of the semiconductor industry. What the United States cannot afford in terms of its global competitiveness and national security

is to take a business-as-usual approach in the face of government-backed global competition for advanced technologies. The United States is ahead in this crucial industry; it should not wait until it has fallen behind to support chip design in the face of the Chinese challenge. On the contrary, with the right policy and financial support, the United States can continue to surge ahead.

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