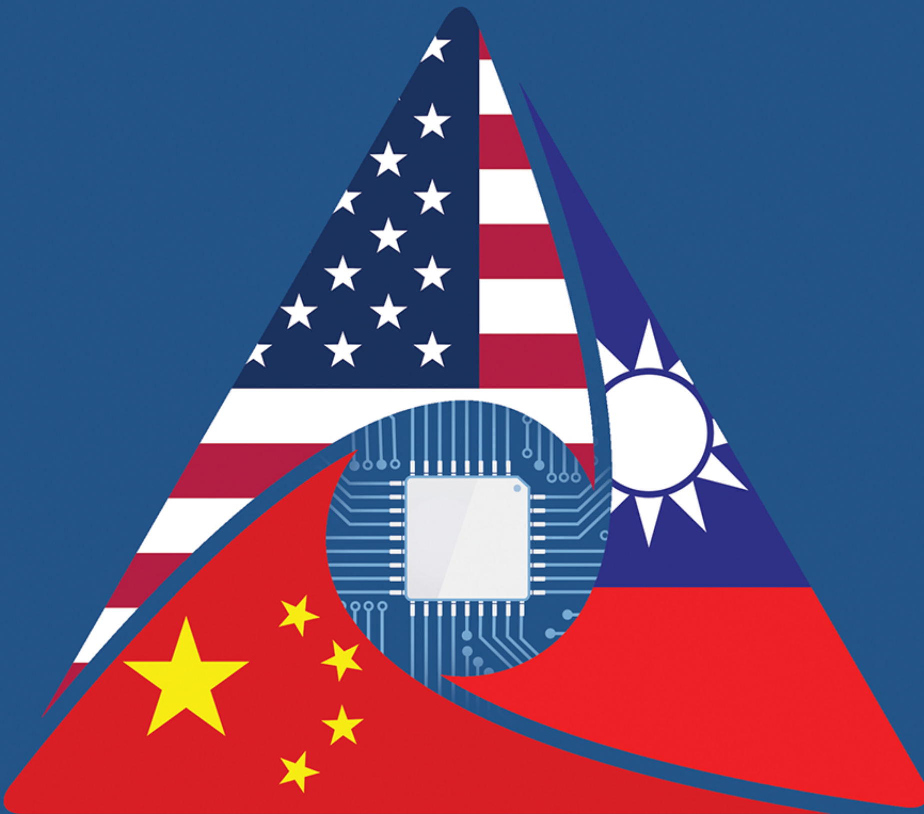

Silicon Triangle

The United States, Taiwan, China, and Global Semiconductor Security

Edited by Larry Diamond, James O. Ellis Jr., and Orville Schell

CHAPTER THREE

An Insurance Policy for Dependence of US Supply Chains on Foreign Providers

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The United States should adopt an "insurance policy" for its overseas semiconductor supply chain exposure through realistic onshoring and other measures that enhance independence and resilience.

Emergent security and geopolitical concerns that were less evident a decade ago now warrant additional policy attention in maintaining commercial semiconductor supply chain resilience in both leading-edge and mature chips; a variety of short- and long-term government policies and business sector options need to be considered to address this challenge.

A special subset of semiconductor supply chain disruptions could lead to the United States losing access—temporarily or for a protracted period—to advanced-semiconductor exports from trusted partners in Asia. For example, this inaccessibility could occur in the event of a People's Republic of China (PRC) blockade of Taiwan or some form of armed conflict on or around the island. A natural disaster could also severely disrupt access, at least temporarily. In view of these threats, the United States should invest in some degree of diversification, especially with regard to the manufacturing of chips, which would diminish short-term economic or strategic damage to the United States—and provide the nucleus of scalable supplementary capacities—in the event of supply chain

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Any views expressed and characterizations made by Dr. Ford herein represent his personal perspective, and not necessarily that of anyone else in the US government or elsewhere. Dr. Ford is grateful for the contributions made by his coauthor on this chapter, but that coauthor has requested public anonymity.

disruptions. Implementation of the CHIPS and Science Act of 2022 should be evaluated by these imperatives.

Beyond the time-limited subsidies available through the CHIPS and Science Act, it is important to recognize the key role of private capital and commercial business decisions—including investment decisions made by US partner–domiciled firms in Taiwan, Japan, or Korea—in realizing US public interests in sustaining additional semiconductor activity over time. The main way to do this is by making this country an attractive place to do business from a cost and regulatory perspective. Both the federal and US state governments have responsibilities to this end. Otherwise, subsidies are a bridge to nowhere.

That said, ensuring access to Taiwan's semiconductor exports should not become a significant factor motivating US decisions to help defend Taiwan. Such a commitment should rest on broader principled and strategic grounds, including Taiwan's global importance to democracy and the world economy. After all, China's interests in Taiwan also rest on its broader political and strategic interests, and potential semiconductor-related benefits or implications will not weigh heavily in Beijing's calculus regarding the use of military force against Taiwan.

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In early 2021, the lead times for the manufacture of semiconductor chips sharply spiked. A previous average lead time of twelve weeks reached fifteen weeks by January 2021, then stretched to seventeen weeks by March and April. These delays triggered an unprecedented global chip shortage and caused several downstream industries to warn of upcoming production deficits. Chip shortages led to major losses for systems integrators—for example, the global automotive industry was estimated to have lost $210 billion in sales in 2021.[1]

The chip shortage of 2021 and early 2022 can largely be attributed to market dynamics—namely, a demand shock resulting from poor industry planning and a subsequent surge in orders emerging from the COVID-19 pandemic. But one particularly stressed class of victims of this sharp swing in orders was carmakers, who were forced to review their practice of maintaining lean inventories as cost-savings strategies. The problem began when new vehicle sales essentially halted in spring of 2020 and the industry drastically cut orders for parts and materials, including the chips needed for a growing number of automotive applications such as touch screen displays and collision-avoidance systems.[2]

Meanwhile, the consumer electronics industry soaked up those unsold chips, as a surge in demand occurred from consumers working from home for personal computing products and more general technology. Then the problem was exacerbated when China's own electronics firms—including multinational champion Huawei—began stockpiling chip supplies in anticipation of further US sanctions.[3] By the time vehicle demand began to rebound in late 2020, chip manufacturers were already committed to supplying major customers in consumer electronics and could not meet resurgent demand.

More important than the 2021 shortage itself, however, may have been the significant media and policy attention it directed to the way that global supply chain fragilities, by creating alarm, ultimately worsened the crisis. This led to a close examination of the United States' dependence on the global chip supply chain.

Despite the well-documented weaknesses in the manufacturing and packaging of chips, the United States still holds the world's strongest position across the rest of the semiconductor supply chain—namely, in semiconductor manufacturing equipment, electronic design automation (EDA), chip design software, and high-end fabless chip design. Less appreciated is the fact that the United States is also home to many of the world's most important retailers and device integrators—that is, end customers of chips who integrate them into valuable consumer products. These systems integrators and original equipment manufacturers (OEMs), such as Apple and auto manufacturers such as GM, capture much of the value of a differentiated final consumer product and hold tremendous influence over the operating decisions of their suppliers, especially those in the chip sector.

Of the various concerns that have arisen about the robustness of the semiconductor supply chain, especially since the COVID-19 pandemic, the most elementary one is the risk that the US strengths in the semiconductor supply chain will be undermined by its domestic weaknesses in chip manufacturing. This chapter explores US semiconductor strengths and weaknesses and suggests short- to medium-term measures that could be taken to mitigate the risk of deep US reliance on overseas manufacturing. We will also suggest new domestic resiliency initiatives and manufacturing competitiveness reforms that will make US supply chains more dependable as the world becomes more fractious.

Before proceeding, we also issue a word of caution. Semiconductor shortages or surpluses from periodic mismatches in supply and demand are a normal feature of this capital-intensive and fast-moving industry, and managing them should remain largely a business matter rather than a responsibility of US government policy. Ford F-150 pickup trucks, for example, would likely still have been backlogged in 2021 for want of, say, window regulator control chips, even if the United States had an entirely autarkic semiconductor supply chain.

As we move increasingly toward a world of intensified trade among like-minded blocs of nations, moreover, the United States will continue to benefit from its reliance on friendly partners and their comparative contributions to a complex international chip supply chain. Thus the medium-term goal of US policy efforts on semiconductors should be to make our rapidly evolving network of trusted participants in the chip supply chain more reliable and attractive. A balanced policy will pursue efficiencies and growth through trade (with particular growth among partners) while assuming some new economic costs as a sort of insurance policy against catastrophic foreign supply chain disruption or manipulation.

To that end, as soon as possible the United States government should aim to do the following:

- Preserve the business competitiveness of its existing areas of innovation and strength in the semiconductor supply chain by maintaining an attractive global investment environment and by continuing to facilitate the availability of skilled workers, including immigrants.
- Subsidize investment in existing areas of weakness, such as advanced-semiconductor manufacturing and packaging, where

medium-term market-driven economics are likely to trail those of even friendly trading partners.

- Incentivize, or itself establish, novel supply chain resiliency mechanisms, including aggregating information, stockpiling, and practicing extended inventory management where the public interest requires more resiliency in light of risks of disruption or strategic manipulation.

In short, the United States should do what it takes to facilitate both domestic production capacity and closer reliance on Taiwan, South Korea, Japan, and other partners that provide key steps in today's semiconductor production supply chain. With such a successful insurance policy, the US commander in chief would not feel his or her national security decision making was constrained in a future Indo-Pacific crisis *due to domestic failures to mitigate supply chain risks alone*. A decision this weighty should be determined by values and strategic interests, not a shortage of microchips or commercial concerns.

US Semiconductor Strengths

The United States remains the world's leader in the design and marketing of advanced chips. Nvidia, Intel, AMD, Apple, and Qualcomm are all at the top of their industries and will remain there for a long time. The US chip ecosystem is built upon historical US leadership in research at universities and corporate research labs.

As described in the previous chapter, the United States is home to ten of the world's top twenty semiconductor design companies, including Qualcomm, Nvidia, and Broadcom. US firms collectively enjoy nearly 90 percent of global market share for the design of leading-edge logic chips, and over half of chip design revenue in general. Through firms such as Cadence, Synopsys, and Mentor Graphics (now part of Siemens), the United States dominates in EDA software tools; together, these three US firms account for 85 percent of the global market and represent an important choke point area for the industry, since there are no presently feasible alternatives to them.

The United States also has leading-edge semiconductor manufacturing equipment companies such as Applied Material, KLA, and Lam Research. Table 3.1 summarizes some of these key US firms across today's supply chain.

Table 3.1. Key US and Non-US Players by Semiconductor Value Chain Step

CATEGORY	VALUE CHAIN STEP	US COMPANIES	NON-US COMPANIES
Inputs	Semiconductor manufacturing equipment	Applied Materials Lam Research KLA-Tencor	ASML (Netherlands) Tokyo Electron (Japan)
	Specialized chemicals and materials	Dow Chemical, DuPont	Tokyo Ohka Kogyo (Japan) Showa Denko (Japan) SK Materials (Korea) Foosung (Korea)
	EDA software	Cadence Synopsys Mentor Graphics (US HQ, German ownership)[a]	Altium (Australia) *Huada Empyrean (China)*
Design and manufacture	Integrated device manufacturers (IDM)	Intel Micron Texas Instruments	Samsung (Korea) SK hynix (Korea)
	Semiconductor designers (fabless)	Broadcom Qualcomm Nvidia	MediaTek (Taiwan) Novatek (Taiwan) Realtek (Taiwan) *HiSilicon (China)*
	Foundries (contract fabs)	GlobalFoundries (US HQ, UAE ownership)	TSMC (Taiwan) UMC (Taiwan) *SMIC (China)*
Assembly, packaging, and test	Outsourced assembly packaging and test (OSAT)	Amkor	ASE (Taiwan) *JCET (China)* UTAC (Singapore)

[a]Owned by Siemens since 2017.

Note: Italics = China-based company

Source: Adapted from Randy Abrams, Tseng Chaolien, and John Pitzer, "Global Semiconductor Sector: The Uneven Rise of China's IC Industry," Credit Suisse, January 2021.

These firms all produce for the US domestic market as well as for customers abroad. For example, the United States in 2019 exported about $8 billion in chips annually to China chip designers, as well as around $4 billion in design tools and manufacturing equipment. The United States also exports around $400 million in raw materials to China, including photographic plates, wafers, and wafer material.[4]

Major US tech firms such as Google, Amazon, and Apple are also both chip designers and chip consumers. As the world's leaders in their respective ecosystems, they lead trends on design and implementation, which are hard to disrupt without the emergence of novel technologies. Their large revenue streams and longer investment time horizons also allow them to invest in new chip designs that may take years to bear fruit. Their order sizes and cofinancing of new production capacity often give them priority in manufacturers' outputs, offering them first access to new generations of technology and helping to insulate them from supply disruption during times of shortage. Their choice of suppliers for components in new products—e.g., for memory in a new iPhone, or a modem chipset—can make or break an upstart manufacturer. And their preferences on logistical arrangements, including location of manufacture, can be negotiated as part of their supply contracts. Thus their influence on an industry's direction should be utilized, not ignored, in considering how to fortify chip supply chains to align with national security issues.

US Semiconductor Supply Chain Weaknesses and Vulnerability

But the picture is not all rosy. The US share of global chip manufacturing has dropped from 37 percent in 1990 to 12 percent in 2020. Chip assembly and packaging—a critical link in the chip supply chain—is also relatively weak, with the United States having only about 15 percent of global market share.

The loss of leadership in leading-edge logic chip production was primarily due to private investment decisions, as US industry chose to concentrate investment on the higher–gross margin fabless design business and yielded the lower-grossing, capital-intensive manufacturing business to Asia. As described in chapter 2, leading companies such as Intel also made strategic errors that contributed to the loss of US leadership.

The decline in trailing-edge chip fabrication was driven by market forces—e.g., lower labor cost and more attractive capital structures in some Asian countries—as well as by better incentives offered by the governments of East Asian nations. As a result, the United States today has almost no commercial manufacturing capacity for legacy logic chips with the node sizes above 28nm.

Manufacturing costs remain much higher in the United States than in Asia. The Semiconductor Industry Association (SIA) estimates that the ten-year total cost of ownership of a new fab located in the United States is now 25–50 percent higher than in Asia, an estimate confirmed by Taiwan Semiconductor Manufacturing Company (TSMC) in connection with its current work to establish two new leading-edge logic fabs in Arizona. Overall, SIA assesses that only 6 percent of the new global capacity will be in the United States if present trends continue. By contrast, China is projected to add 40 percent of new global capacity over the next decade.[5]

Beyond manufacturing, there is also more recent industry concern about the strength of the US pipeline for innovation through new market entrants across other links of the semiconductor supply chain, even in current areas of strength such as semiconductor design and equipment. The perspectives of private investors are illuminating here.

Consider the example of venture capital (VC) as a development route for a prospective US semiconductor manufacturing equipment startup firm. In the 1990s, the semiconductor industry was one of the hottest sectors for US venture capital. Today, while overall US VC investment in semiconductors has grown, the sector has declined as a share of the US total VC investment. Some investors suggest that capital losses in the cleantech sector early in this century created distrust among US VC investors in the hardware industry, compared to software, which is less capital-intensive and offers quicker returns. Furthermore, advances in consumer internet technology also moved entrepreneurial interest away from semiconductors.

The success of a startup ecosystem relies in part on the number and variety of experiments that are attempted therein: the more experiments there are across a wider variety of areas, the better the chances for a breakout success. But for US semiconductor design and equipment startups in particular, two main issues now inhibit these experiments. First, as touched on in the previous chapter on industry and technology trends, it takes roughly $30 million of financing to even prove out the viability of a new prototype chip design, and another $100 million or more to get to volume production. Second, the potential universe of acquiring companies has become more limited because of public market consolidation; fewer buyers means smaller acquisition premiums and smaller exits for venture investors. Huge capital costs, combined with a small buyer universe and smaller and less profitable exits, do not make for an attractive area for investment. When combined with today's macroeconomic environment characterized by higher interest rates, this limitation risks creating a cycle of diminishing interest and funding in US semiconductor startups.

While US semiconductor VC investments easily constituted the majority of global semiconductor VC investments from 2000 to approximately 2017, the US portion has since declined significantly. VC semiconductor investments in China, however, have not lagged and have largely filled that gap.

Recent Policy and Industry Responses

A series of high-profile industry announcements have followed the pandemic-era chip shortages. Together, these new investments have the potential to form the core of a sort of insurance policy against catastrophic consequences for the United States if global chip supply chains were to be severed, particularly in manufacturing.

First, in 2020, Taiwan's TSMC announced that it would build a $12 billion fab in Arizona, scheduled to begin production in 2024. In late 2022, TSMC's founder indicated that a second, more advanced fab would be added to that same Arizona site.[6] Samsung and Intel have also announced $17 billion and $20 billion investments, respectively, to increase manufacturing capacity in Texas and in Ohio.[7] In addition, in mid-2022, Taiwan's GlobalWafers announced a $5 billion investment in a new silicon wafer manufacturing facility in Texas.[8] Qualcomm and GlobalFoundries also announced a $4.2 billion purchase agreement to fund expansion of GlobalFoundries' New York facility.[9] The US firm Micron, meanwhile, announced a $40 billion investment in domestic memory chip manufacturing through 2030, which it claimed would increase the US market share from 2 percent to 10 percent.[10] These announcements are motivated by a combination of commercial interests—that is, customer preferences—as well as by the raft of state and federal government subsidies proposed or enacted in response to the shortage of chips and fears of foreign supply chain disruption. Whatever the motivations, they represent the beginning of what could be a very significant shift in this sector.

In his December 2022 speech marking the "tool-in" of the company's first Arizona fab, TSMC founder Morris Chang described that stage in the construction process (and by extension the current state of geopolitically driven semiconductor supply chain reconfiguration) as "the end of the beginning."[11] The sections that follow describe which beginning policy steps are already being taken in the United States, and what more could be done to improve the resilience of the US sector.

Federal Spending

At the federal level, a consequential 2020 SIA and Boston Consulting Group (BCG) industry association report on global government incentives for chip manufacturing set off a flurry of executive and legislative activity.[12] The report modeled the impact of several potential US policy approaches—a baseline in which the US share of global manufacturing would further decline from 12 percent to 10 percent by 2030, a $20 billion federal subsidy program that would allow the United States to sustain its current 12 percent market share, and a $50 billion subsidy program would result in an increase to 14 percent. Implicitly, the report advocated for the highest tier of government involvement in order to reverse a decline in US semiconductor manufacturing—and assure at least a minimum (and thereafter potentially scalable) degree of domestic production capacity for critical needs should global chip supply chains be severely disrupted. These investment figures ultimately helped inform the proposed $52 billion "CHIPS for America" manufacturing grant program as part of the US Senate's US Innovation and Competition Act of 2021.

Elements of that bill were passed as the CHIPS and Science Act on a bipartisan basis in July 2022, after significant legislative wrangling between the two congressional chambers. Its goal is to boost American semiconductor research, development, and production. It contains the following provisions:

- $52.7 billion for manufacturing, workforce development, and research, including $28 billion in manufacturing incentives for leading-edge logic and memory chips (largely grants, but also $6 billion in loans and loan guarantees)
- Approximately $10 billion in grants and loan guarantees specifically for mature or current-generation chips and industry suppliers
- $11 billion for a National Semiconductor Technology Center and a National Advanced Packaging Manufacturing Program, as well as National Institute of Standards and Technology (NIST) metrology (chip measurement) R&D programs
- $2 billion for Department of Defense chip technology development and domestic prototyping needs
- $500 million focused on international semiconductor supply chain security

These funds are to be distributed over a period of five years, with about half of the total to be expended in 2023. The bill also includes a grant clawback "guardrail" clause, requiring that firms receiving grants will not significantly expand semiconductor manufacturing or joint technology development in China or other countries of concern (legacy chips, defined as 28nm or above, are excepted).[13]

This all represents a very important start. There are, however, areas for further improvement:

As the rules for these CHIPS Act subsidies are established by the US Department of Commerce and disbursement proceeds, the focus must turn to execution of these projects. And it is fair to regard this targeted subsidy of semiconductor manufacturing as a public experiment. If it fails, there will be little justification for similar efforts in other critical technology areas, and the US effort to develop what has been termed a "modern industrial and innovation strategy" might be regarded as having failed.[14] To preserve bipartisan support for effective competitive strategy in the technology arena, it will be essential to prevent cronyism and protectionism, or policy-maker capture by particular business, labor, or local political interests, from distorting and discrediting these efforts.

Given the primary goal of establishing at least minimal onshore manufacturing capabilities, *awards of funding should be made to the firms—whether headquartered domestically or in friendly jurisdictions abroad—that have the best chance of executing on this promise from a technology risk and operational efficiency perspective*. The CHIPS Act effort will be at risk and future efforts much less likely to win support if the United States does not at least manage to get two fabs up and running that are capable of producing commercially viable, leading-class logic chips at competitive yields within the program's five-year time frame.

Federal Tax Efficiency

Semiconductor manufacturing is a notably capital-intensive industry. Industry participants report that, given the level of private investment that goes into upgrading or expanding production facilities each year (many multiples of any public grants), tax efficiency on that capital investment is an even larger motivator than direct public spending. To that end, perhaps more impactful than the CHIPS and Science Act's direct expenditures was its 25 percent (Section 48D) investment tax credit for capital expenses for the manufacturing both of semiconductors themselves and of semiconductor manufacturing equipment over the period 2023–26, which is estimated to be worth as much as $24 billion (depending on private investment levels).[15] This sector-specific measure built upon the more general tax efficiency measures of the 2017 Tax Cuts and Jobs Act (TCJA), which included an overall corporate tax rate reduction from 35 percent to 21 percent (below that of many Organisation for Economic Co-operation and Development [OECD] nations), as well as a 100 percent bonus depreciation tax deduction for short-lived capital assets, such as equipment used in semiconductor manufacturing facilities (a depreciation currently set to phase out from 2023 to 2026). Both of these pieces of legislation represent important moves into tax-based investment incentivization.

But there are further areas for improvement here as well:

- Well over half of the cost of a new semiconductor fab derives from the equipment purchased by the manufacturer to build production lines. *Extending full tax depreciation for short-lived capital assets beyond 2022* could therefore improve the competitiveness of US semiconductor and semiconductor equipment manufacturers.
- Modern semiconductor and semiconductor equipment manufacturers reinvest significant portions of their revenue into research and development each year in order to sustain leading-edge capabilities. As part of TCJA negotiations, deductions of US firm R&D spending are now (since 2022) required to be taken over five years, instead of immediately in the year incurred. *Reverting to full tax deductions of R&D expenses on an annual basis* would benefit a broad swath of knowledge investments in this and other critical research-intensive industries.

Federal Regulatory Reform

The time-consuming and burdensome procedures mandated by the 1970 National Environmental Policy Act (NEPA) will impede the growth of the US semiconductor industry, despite the passage of the CHIPS Act. In the United States, a construction project classified as a "Major Federal Action," for instance, could be subjected to a lengthy review process, lasting 4.5 years on average.[16] In comparison, other advanced democracies such as Germany and Canada—neither of which is usually reticent about imposing regulatory burdens upon the private sector—have more efficient permitting processes than does the United States, and both generally conclude reviews within a mere two years.[17] Construction of fabs involving federal funding could trigger this level of heavy environmental regulation, with associated permitting delays.[18]

So far, only limited steps have been taken at the federal level to address this risk. For example, Title 41 of the Fixing America's Surface Transportation Act of 2015 (FAST-41)—made permanent in the 2021 Infrastructure Investment and Jobs Act—included provisions to hasten the federal permitting process by improving early consultation, interagency coordination, transparency, and accountability in specified sectors (e.g., highway construction).[19] In November 2021, Senators Portman, Hagerty, and King added an amendment to the Fiscal Year 2022 National Defense Authorization Act that incorporates sectors relevant to national security, including semiconductors, into the FAST-41 fast-track process.[20]

President Biden also announced the launch of a sector-specific interagency expert working group on permitting and permitting-related project delivery issues for high-tech manufacturing.[21] This group is to build on CHIPS Act provisions by boosting interagency coordination as well as federal-state coordination, consistent with the administration's general permitting plan launched in May of 2022.[22] Federal-state coordination to avoid redundancy in regulations and oversight has been identified by analysts as a particularly important area for improvement.[23]

Further areas for improvement are these:

- Despite efforts to categorically exempt semiconductor fabs from burdensome environmental reviews—the US Chamber of Commerce, for example, wrote to the secretary of commerce in the spring of 2022 urging the department to exempt semiconductor fabs from lengthy NEPA reviews[24]—facilities receiving CHIPS Act funds are expected to be subject to existing NEPA regulations.[25] Given that leading-edge logic technology cycles are themselves on the order of two years, this permitting process barrier, if applied to fabs, could prevent the United States from ever producing the world's most advanced chips. Indeed, since the NEPA process for "Major Federal Actions" takes more than *twice* as long as this cycle, applying NEPA rules to chip fab facilities would ensure that US-located manufacturing falls progressively further behind the state of the art. *Care should be taken to ensure that federal financing intended to speed the development of this sector does not inadvertently slow it.*

- While direct Environmental Protection Agency (EPA) permitting itself may account for only a small portion of regulatory requirements, a new project must manage many other federal and state regulations that often require EPA's input. For example, in Arizona, the Department of Environmental Quality (DEQ), a state agency, grants permits that are required under the federal Clean Air Act (CAA), the Resource Conservation and Recovery Act (RCRA), and the Clean Water Act (CWA), as well as other state-level regulations. These permit processes also receive input from the EPA. *A policy of timely EPA reviews for critical industries* such as chip fabs could therefore improve private investor confidence in project delivery schedules—which is particularly important given their large up-front capital outlays and the need to coordinate long-lead-time equipment orders from dozens of vendors.

Flexible air and water permits are another potential approach to allow companies to make changes to their plants without triggering new environmental reviews. Flexible permitting is a way to avoid EPA or other federal permitting delays within willing host communities while preserving environmental performance. For example, Oregon's Plant Site Emissions Limit (PSEL) program allows such flexibility as long as overall emission limits are met. Intel has cited this flexibility as the reason behind saving "hundreds of business days associated with making operational and process changes to ramp up production," and added that without it they would have had to move production away from Oregon.[26]

According to a 2017 McKinsey report, indirect "scope 2" emissions, largely from purchases of power generated off-site to run production facilities, are the largest contributors (45 percent of the industry's total) of greenhouse gases (GHG) from semiconductor companies.[27] Access to not just cheap power, but low-carbon power too, has become a major factor for companies to decide on fab locations. The United States in general is quite competitive in this regard, compared to the dirtier power grid mixes in China, South Korea, Taiwan, and Singapore. Direct "scope 1" emissions (35 percent) also contribute to sectoral GHG emissions. They are associated with high-global-warming-potential process gases in tasks such as wafer etching and chamber cleaning, as well as leakage of heat-transfer fluids into the atmosphere when used in chillers to control wafer temperature. Meanwhile, semiconductor "scope 3" emissions (roughly 20 percent) arise from suppliers, chemicals and raw materials, and transportation to customer facilities. Large chip buyers and OEMs themselves are increasingly pushing suppliers to improve the environmental performance of their operations as part of consumer-oriented efforts to green their own supply chains.

- Especially given the intense global competition for semiconductor manufacturing as well as government climate objectives, *care should be taken not to inadvertently introduce new chip regulatory barriers*. For example, the Inflation Reduction Act of 2022 subjects fabs to EPA oversight on GHG emissions.[28] While this oversight per se is a relatively modest action focused on reporting, it should be considered against the totality of compliance costs that this sector's investments face in the United States compared to attractive sites abroad. The EPA's March 2023 proposal to set strict "zero-level" per- and polyfluoroalkyl substance (PFAS) standards for drinking water, for example, was not aimed at the semiconductor industry, but fabs rely on these fluorinated chemicals for chip manufacturing.[29]

It is understood that reducing emissions and improving resilience of the semiconductor supply chain are both important government objectives, but without care in implementing such rules, issue fratricide could occur that betrays all such equities—such as if environmental regulations undermine semiconductor initiatives and imperil US job growth while leaving global chip manufacturing concentrated in foreign locales with dirtier energy grids and lower standards.

Federal Immigration Measures

The United States does not have a direct STEM (science, technology, engineering, mathematics) workforce shortage problem in semiconductor manufacturing today—there simply not being much demand for labor today at all, given low levels of manufacturing activity. But the industry does face structural workforce-related problems that the traditional solutions of more fellowships, internships, and stipends to improve the "pipeline" of STEM graduate students will not be able to solve as labor demand from new semiconductor investments does materialize.

Some US academics have pointed out that as the United States has foregone actual domestic production of the technologies it invents, the way that we educate students, particularly in electrical engineering, a core discipline of semiconductor development, has ossified. Rather than training their students as broad system designers—that is, people who can take ideas from disparate disciplines and create new systems by merging those ideas—most US electrical engineering departments now focus their teaching and research narrowly on computing and communications applications. This practice stands in contrast to, for example, US computer science programs, whose curricula and culture emphasize learning coding tools and principles to solve many different practical problems. The consequence is that electrical engineers see more limited applications for their knowledge—indeed, domestic enrollments in the field have plummeted, as prospective students see more interesting opportunities elsewhere. By contrast, US computer science graduates can enter a variety of compelling industries, and enrollments have grown steadily.

This issue is solvable. More domestic activity across the entirety of the semiconductor value chain, including manufacturing, will let students see new applications of their work and will motivate universities to adjust. New semiconductor manufacturers and suppliers will bring to the United States not just their production facilities, but also their supporting industrial R&D apparatus; these R&D ecosystems will facilitate today's missing demand signal and help translate university training to evolving commercial needs. (Given the fast pace of semiconductor manufacturing in particular today, commercial know-how far exceeds what is presently taught in universities.)

But it will take time. As the United States addresses these issues over the long term, labor markets will naturally adjust to actual needs. In the transition, we can look to high-skilled immigrants to function as a bridge to meet increased demand for labor in domestic semiconductor (or other advanced technology) manufacturing.

As the politics of broad-based immigration law reform continues to confound a US Congress long polarized and paralyzed on such topics despite widespread popular dissatisfaction with the immigration status quo,[30] the only recent reforms relevant to semiconductors have been narrow administrative efforts under executive purview. The Biden administration, for example, has been focused on increasing retention of international STEM students in the US workforce—that is, domestically employing a higher proportion of our relevant engineering graduates who come from abroad. (International students compose around two-thirds of graduates today in semiconductor-related fields.[31]) In January 2022, the Department of Homeland Security added twenty-two new STEM fields to the Optional Practical Training (OPT) program, allowing more STEM graduates on F-1 visas to work in the United States for a longer time after graduation.[32] Such measures, however, are inadequate to the need.

Further areas for improvement, therefore, include the following:

- *Additional legislative measures are needed to capture skilled immigrant talent for the US semiconductor industry*. Administrative tweaks to visas offer only minor help compared to larger and

> more substantive changes to programs such as the H-1B visa program or green card caps, either of which would require legislative action. While both US industry and the public appear to support increasing skilled immigration,[33] targeted bipartisan reforms have been held hostage in broader political debates on illegal immigration.

This legislative reticence to address immigration-related measures—however important—was reflected in the legislative history of various proposed semiconductor and competitiveness bills, elements of which were eventually passed in the CHIPS Act, which generally shunned immigration in favor of education and workforce-training provisions, which are less likely to have significant impact, especially in the short term. Representative Michael McCaul's (R-TX) and Senator John Cornyn's (R-TX) original Senate bill from June 2020, for example—the Creating Helpful Incentives to Produce Semiconductors (CHIPS) for America Act—did not contain any provisions for immigration reform or attracting STEM graduates to work in the semiconductor industry.[34] Similarly, while the related Restoring Critical Supply Chains and Intellectual Property Act of 2020 sponsored by Senator Lindsey Graham (R-SC) added further emphasis on domestic educational pipeline reforms, it also did not address skilled immigration.[35]

Reflecting the broader scope of contemporaneous proposals from the House of Representatives, the America COMPETES Act (HR 4521)—passed largely along party lines in February 2022—added a number of skilled immigration measures not found in the similar June 2021 Senate bill. That later bill included exemption from annual green card caps for international STEM PhDs and master's degree holders in "critical industries" such as semiconductors.[36] It also included measures from Representative Zoe Lofgren's (D-CA) proposed 2021 Let Immigrants Kickstart Employment (LIKE) Act, which would have created a new visa category for immigrants interested in establishing venture capital–backed startups. Moreover, HR 4521 would have established US STEM scholarships funded by a $1,000 supplemental surcharge for green card recipients. Perhaps reflecting the complicated bargaining and political valences involved in any immigration-related legislation, the House measure also included substantive pro-union proposals that could increase costs, including prevailing wage requirements on fab construction projects receiving federal funding, $4 billion to expand apprenticeship programs, and union neutrality requirements for employers receiving federal dollars under the Act.

Ultimately, these House immigration provisions proved politically unpalatable in the Senate—even many Senate Democrats opposed them in conference. Thus, they were dropped from the final stripped-down legislation package, even as some workforce development and union measures were retained.[37]

Given Congress's failure to pass any meaningful immigration reform, *legislative skilled immigration measures are urgently needed* to improve the impact of the CHIPS Act. Such measures would also be helpful in increasing private funding for domestic semiconductor manufacturing facilities in the near to medium term. These efforts should be paired with incentives to train Americans as both hardware and materials engineers, as well as the skilled tradesmen and technicians needed in constructing and operating semiconductor fabs or semiconductor equipment manufacturing and packaging facilities, as described in chapter 4 of this report.[38] Such initiatives would both help smooth a rapid labor market transition and improve the chances of success for timely construction and cost-effective operation of new manufacturing facilities.

- Toward these ends, the United States should consider *waiving numerical H-1B visa caps and making them available to all international students who complete a STEM graduate program at an accredited US university*. Until the United States can dramatically increase its domestic pool of relevant science and engineering talent (a task that will, at a minimum, take a decade), it will not be able to restore its international competitiveness in high-tech manufacturing.
- In parallel, community colleges and related industry apprenticeships located within the region of a semiconductor manufacturing cluster should be supported to provide the skilled trade and tool

operators that constitute the bulk of jobs in fabrication facilities. Given the efficiencies realized through geographic clustering of semiconductor production and the relative lack of US labor mobility for these trades as compared to engineers, *a regional focus for such technician-oriented programs is important.*

State Incentives

Mitigating the risk of reliance on foreign semiconductor manufacturing through increased domestic production will rely as much on the policies of individual US states working in their own economic self-interest to attract private investment as it will on the strategic actions taken by the federal government. To the extent that the cost of doing business is higher in the United States than in Asia, it is the US states that hold many of the policy levers that could help narrow that gap, including local income and property taxation policies, support for physical infrastructure, building permits, and access to high-quality electricity and water supplies. US states with existing semiconductor industry footprints have been the most proactive in trying to facilitate new investments. The following paragraphs survey illustrative examples of where state governments have, to date, stepped in to support various initiatives:

Arizona

Based on employment statistics, semiconductor manufacturing has consistently been among the three largest manufacturing sectors in Arizona, where the state's Qualified Facility Tax Credits (QFTC) and Quality Jobs Tax Credits (QJTC) are among the chief incentives for semiconductor companies.

The QFTC was established by the Arizona legislature in 2012, and subsequently amended in 2016, 2020, and 2021, to promote the location of new or expansion of existing headquarters and manufacturing or R&D facilities in the state.[39] In 2021, TSMC Arizona Corporation was given a preapproved tax credit in the amount of $30 million.[40] In the 2014 QFTC annual report, two facilities from Intel Corporation are also listed as having received such tax credits—the first received $10.9 million, and the second received $6.7 million. Three other preapproved companies also received around $2 million in total. Table 3.2 lists companies involved in semiconductor manufacturing that received tax credits under this program, and illustrates the importance of tax credits not just for a single fab, but for the health of complementary suppliers and technology vendors.[41]

Table 3.2. Arizona Semiconductor Tax Credit Recipients

YEAR	COMPANY	AMOUNT GIVEN	NOTES
2014	Intel Facility 1	$10,860,000	
	Intel Facility 2	$6,680,000	
2015	Essai Inc.	$320,000	Essai, since acquired by Advantest; leading supplier of semiconductor final-test, system-level test sockets and thermal control units
	ASM America, Inc.	$1,280,000	ASM is a leading supplier of semiconductor process equipment for wafer processing.
	Intel (Chandler)	$10,860,000	The Chandler fab was designed to use larger equipment required for manufacturing wafers.[a]
	Intel (Ocotillo)	$6,680,000	
2016	Essai Inc.	$260,000	
2017	Infineon Technologies Americas Corp.	$600,000	Semiconductor manufacturer
	RJR Technologies	$398,500	Innovator in preapplied adhesive technology for semiconductor industry
2018	Fujifilm Electronic Materials USA Inc.	$1,020,000	Produces high-purity chemicals and materials for semiconductor manufacturers
	Texas Instruments Incorporated	$700,000	Semiconductor manufacturer
	Infineon Technology Americas Corp.	$500,000	

Table 3.2. (*continued*)

YEAR	COMPANY	AMOUNT GIVEN	NOTES
2019	Intel Corporation	$540,000	
	Intel Corporation	$11,600,000	
	Semiconductor Components Industries, LLC	$4,000,000	Designs and manufactures semiconductor components. Now known as ON Semiconductor or Onsemi.
	Fujifilm Electronic Materials USA Inc.	$1,020,000	
2020	Auer Precision Company LLC	$344,827	Leading contract manufacturer of precision metal and thin-film polymer parts for semiconductor markets
	Intel (Ocotillo)	$28,900,000	
2021	Advantest America Inc.	$4,200,000	Japanese manufacturer of automatic test equipment for semiconductor industry
	Essai, Inc.	$1,180,000	
	Intel Corporation	$420,000	
	Intel Corporation	$2,300,000	
	Intel Corporation	$21,600,000	
	Intel Corporation	$8,140,000	
	Microchip Technology Inc.	$1,200,000	Manufactures microcontroller, mixed-signal, analog, and flash-IP integrated circuits
	TSMC Arizona Corporation	$30,000,000	
	Foresight Technologies, Inc.	$242,895	Provides critical machine parts and subsystems for semiconductors

[a]Don Clark, "Intel Arizona Plant to Remain Idle," *Wall Street Journal*, January 14, 2014.

In March 2021, Arizona's QFTC was expanded via HB 2321 to increase the cap from $70 million per year to $125 million per year.[42] The bill passed with strong bipartisan support.[43]

In addition, Arizona's Qualified Jobs Tax Credit provides nonrefundable income and premium tax credits to qualifying taxpayers—$3,000 per year for each continuously maintained job for up to three years.

Texas

In November 2021, South Korea's Samsung announced the construction of a new $17 billion fab in Taylor, Texas (about forty miles north of Austin), where Samsung has operated a separate fab since 2004.[44] This investment was expected to include $6 billion in property improvements and $11 billion in machinery and equipment. While Texas is attractive to employees because it levies no state income taxes, localities within the state do have high property taxes. Taylor, for example, has a total property tax rate of 2.54 percent.[45] To offset their high rates, state and local governments in Texas have reduced the cost of business for prospective semiconductor manufacturers through both tax relief and regulatory easing. Subsidies toward the Samsung fab in Taylor include these:

- A $27 million Texas Enterprise Fund grant[46]
- A $20,000-per-employee bonus from the state for hiring veterans[47]
- $67 million in road improvements at the state level, and $120 million in road improvements at the county level, plus bonds to pay for $18 million in water/sewer extensions
- 92.5 percent of city and county property taxes abated in the first ten years, 90 percent in the next ten years, and 85 percent in the following ten years—for a total estimated value of $467.8 million over 30 years
- Additional property tax abatements of $314 million over ten years from the local school district[48]
- Expedited permitting and reimbursement for city-level permitting development review costs
- A federal capital gains tax break (since the property is in a federal Opportunity Zone)

Additional commitments to Texas in the semiconductor manufacturing sector have followed. Texas Instruments (TI) announced a modern twelve-inch-wafer-based fab in Sherman (sixty-five miles north of Dallas) in November 2021, with potential for up to four fabs on the new site.[49] TI's investment level is expected to be around $30 billion. The city of Sherman has subsequently filed tax abatement proposals for each fab plant for 2025, 2032, 2037, and 2045, which would yield a total of $148 million in tax relief over ten years, a 90 percent abatement for TI.[50] Later, in June 2022, after GlobiTech, a subsidiary of Taiwan's GlobalWafers, announced an expansion of silicon wafer production in Sherman as well, it was set to receive a Texas Enterprise Fund grant of $15 million and a $10,000 bonus per hired veteran.

To be sure, these efforts have come under some criticism. The Texas Enterprise Fund, for example, has been called "crony corporate welfare"—in particular, some argue that cities will lose revenue and freedom of association by catering to Fund-preferred investments, or that innovation could ultimately be hampered due to a concentration of human capital in a small collection of large firms.[51] Criticism has also been directed toward recipient companies for exploiting their grants to mischaracterize the number of jobs required or actually created under the contract.

Ohio

A newer entrant to attracting semiconductor firms is Ohio. In June 2022, HB 687 became law. It provides $600 million for performance-based onshoring incentive grants aimed at making Ohio "more competitive with Asian markets"; $101 million for water and wastewater infrastructure improvement; $205 million for state and local roads; and $300 million for water reclamation facilities.[52] Notably, to qualify for these funds, companies must have their corporate headquarters in the United States, incur the majority of R&D expenses in the year preceding tax credit approval within the United States, and build and operate semiconductor wafer manufacturing factories in Ohio.[53] Accordingly, unlike the more broad-based competitiveness measures described in Arizona and Texas, the Ohio bill was seen as tailored specifically to Intel: a few months before, Intel had announced a $20 billion investment in the state, and was now being wooed to build two new fabs, supported by up to $2 billion in state incentives.[54]

There is no one ideal policy model that emerges from this interstate competition, but it is on the whole healthy that states see it as important to offer a hospitable location for semiconductor fabs, and such efforts are likely to redound to the United States' net benefit in reshoring a core manufacturing capability. Nevertheless, further areas for improvement include these:

- *Geographic clustering matters for semiconductor manufacturing.* TSMC's leadership expects that, compared to their fab and supplier clusters in Hsinchu, Taiwan, their upstart Arizona facilities will cost 50 percent more to operate. They estimate that perhaps half of that increase will be due to the lack of geographic clustering of the requisite spare parts, equipment, service firms, and workers that help improve factory uptime and yields. States are free to choose and compete with one another on regulatory and policy strategies, and it is to America's benefit that they do so because they can play a key role as "innovation laboratories" in devising better ways to catalyze a US semiconductor renaissance. *But it is also in the broader national interest that individual states with advanced manufacturing endowments remain attractive places to innovate and do business in order to promote such clustering.*

To that end, ease of doing business across US states remains a key consideration for semiconductor firms, which are weighing investment opportunities around the world. While no one state-level condition will dictate outcomes, indices of state-level economic freedom (such as those calculated regularly by the Cato Institute) provide a good list of possible inducements. These include both fiscal measures—such as state taxation, local taxation, government consumption, and investment—and government debt and regulatory policies, including land-use rules, health insurance markets, and labor-mobility restrictions such as occupational licensing.[55]

Among US states, Arizona ranks highly for its ease of new business entry, liberalized pricing, right-to-work laws, and its E-verify mandate. Texas, meanwhile, ranks the highest in the nation for the freedom of its labor market, including right-to-work laws, no additional state minimum wage, and optional workers' compensation coverage. Ohio, by contrast, without right-to-work laws, ranks lower even than other Rust Belt states such as Indiana, Michigan, and Wisconsin. New York, another potential locus for semiconductor manufacturing given GlobalFoundries' operations there, actually ranks last in Cato's economic freedom index, given its high state and local taxes, land-use regulations, and occupational licensing rules.

- *California merits special attention.* Although Silicon Valley has long lost much of the integrated circuit manufacturing for which it was once known, it remains an important locus for other links in the US semiconductor supply chain, including as the headquarters for globally dominant semiconductor equipment manufacturers (such as Lam Research, KLA, and Applied Materials), as well as powerful OEMs and device integrators (such as Apple or Google) and a host of chip design firms (from small to large players, including Qualcomm and Nvidia). California is also home to top engineering schools such as UC Berkeley, Stanford, and Caltech, whose graduates can help staff these, and prospective future, semiconductor firms.

California, however, has also come under scrutiny for its increasing cost of doing business—which has led some firms, including tech firms, to decamp.[56] Moreover, the state ranks poorly on national measures of economic freedom, and lacks a right-to-work rule; also, the legislature has continued to increase a statewide minimum wage of $15 per hour, which is already high by national standards. Perhaps more importantly, rent control rules in California discourage the construction of new rental housing, and local development policies, high construction labor costs, and clean energy–related building codes have all conspired to severely restrict housing supply in desirable coastal areas.[57] An additional issue is the use of the 1970 California Environmental Quality Act (CEQA), which not only requires environmental mitigations for major construction projects but also permits citizen and interest group lawsuits to force additional analysis and delays, increasing costs.[58] While the state has taken some steps to alleviate local building restrictions—such as by challenging single-family housing zoning—firms still report that wages for comparable employees in metropolitan areas of the state exceed those required to attract talent in other parts of the country.[59]

It is hard to imagine a semiconductor (or other critical-technology) renaissance in the United States in which California does not play an important role, but California's regulatory structure makes this more challenging. One hopes that California's own relatively weak competitive posture will not undermine chances for a broader American high-technology industrial renaissance, but problems with the ease of doing business in the state arguably have global implications that may not be fully appreciated in local or state politics.

Novel Public Measures to Improve US Chip Supply Chain Resiliency

Get Better Data

As embedded semiconductors move to the center of our economic vitality and lives, we find ourselves in much the same position on semiconductors today as during the early 1970s with energy. Up until that point, the US energy system was basically seen as the exclusive province and responsibility of major private sector consumers and producers. The federal government did not even collect proper supply-and-demand statistics. When the dual energy crises hit—and national security and social interests, built up around what had been seen as a purely commercial matter, began to reveal themselves—our adversaries abroad were the first to realize how to exploit them.

One result of the 1970s oil embargoes was the (somewhat controversial) creation of what would become the US Department of Energy. Less controversial was the establishment within it of a federal Energy Information Administration (EIA), to which Congress gave power to compel the provision of energy trade and pricing data across a variety of fuels and technologies from major US energy industry participants. That commercially sensitive data, in turn, would be professionally managed by an independent agency for the creation of publicly appropriate and comprehensive energy-statistics databases, forecasting models, and technical policy analyses.[60]

EIA's success in improving the transparency of the US energy market should be a model for our country's current information deficit on the strategically important semiconductor sector. If we are as a country to meet the competitive challenges presented by global supply chain risk and China's potential manipulation of such dependencies for strategic advantage, US policy makers in the executive branch and national legislature—and indeed in state governments as well, for the reasons outlined above—should be better equipped for the complex decisions involved in this arena.

Remarkably little is actually known in detail about the various streams that make up the semiconductor supply chain—especially the sourcing for raw materials and the types of semiconductors. The semiconductor sector has built exquisite mechanisms to take advantage of global variations in cost margin, economies of scale, labor, capital quality, pricing, technical comparative advantage, and logistics architectures. But most of this optimization has taken place on a disaggregated basis and in response to market forces. As a result, there is no good way for policy makers—or market participants themselves—to understand "who's who" across the complete supply chain or to easily perform analyses of supply chain risk with regard to questions of potential ownership or control by unfriendly entities. Better data could improve decision making around semiconductor technology export controls and in mitigating global supply chain disruptions in the near to medium term.

What have we already tried, and what are the options going forward that would help build better supply chain information capabilities?

Existing US government public trade databases—such as the International Trade Administration's modernized Exporter Database (EDB), which presents annual dashboards on US merchandise exporter characteristics, or the US Census Bureau's tracking of goods exports—do not disaggregate data into categories specific enough to be useful for the semiconductor sector. Nor do multilateral economic institution databases such as those of the International Monetary Fund (IMF) fare better in offering insight into the specifics of semiconductor supply chains.

In one effort to inform the planning and design of potential programs to incentivize investment in domestic semiconductor manufacturing facilities and to respond to the chip shortages of the time, the Department of Commerce launched a "voluntary" semiconductor RFI (request for information) in September 2021 that sought commercial data from both major global producers and consumers on a two-month timeline. The request included the following information:

- A description of the company's role in the supply chain
- Technology nodes, semiconductor material types, and device types the firm provided
- Estimates of annual sales for 2019 to 2021
- Products with the biggest backlog—including attributes, sales, location of fabrication, and packaging and assembly
- Each product's top three customers
- Estimated lead times for top products
- Bill-to-book ratio
- Inventory for inbound, in-progress, and outbound product
- Questions regarding firm strategy for allocating available chip supply
- Questions regarding what might be needed to increase production capacity[61]

Because this novel request met a cold reception among both domestic chip buyers and foreign partner suppliers,[62] it is unclear how successful the response rate was, and Commerce eventually published a very general public summary of findings from the request.[63]

One alternative pathway to getting more-detailed data would be through executive action to actually impose licensing requirements *on semiconductor-related materials, equipment, and technology.* Importantly, license requirements would be used not to impede supply chain transfers, but rather to provide visibility and data. Even where presumptively approved, the mere existence of licenses as records of transactions would offer valuable visibility into what is moving, where it is moving, and to whom.

Of course, industry may resist the paperwork burden of licensing the export of complex products that move at scale through global supply chains. And in the past, it may have been more worthwhile to forego the availability of such information in the name of market-transactional efficiency, especially where it was assumed that export controls had little purpose. But given the emerging national security stakes now—both the risks to Western semiconductor firms of being displaced by state-subsidized firms from China and the risks to Western governments of being manipulated by economic dependencies on those firms in China—the balance has shifted in favor of acquiring better information that can ground policy making on export control and supply chain resiliency questions.

Indeed, the Department of Commerce already obtains a great deal of information about semiconductor-related exports through its Bureau of Industry and Security (BIS). So even if it did not impose additional requirements on companies, it could do much more with the information it already has by sharing it more widely with interagency partners, including the intelligence community, and with Congress (albeit in a more summarized and less commercially sensitive form). Especially in the era of China's "military-civil fusion" policies, such export information is important in any analysis of the capabilities China is acquiring. We need to have a clearer understanding of how well China is doing in meeting its industrial policy targets, and what technologies are being made available to China's military or security services. Such information would also underpin efforts to conduct technology net assessments that compare Western and Chinese capabilities, assess trends of each, and chart relative rates of progress. In short, such information would help us draw out the economic, military, and strategic implications of this globalized, complex supply chain. In order to permit the government to benefit from such analyses, *Commerce should systematically share more of its information with other agencies.*

The sophistication of such analyses—either by Commerce or through another suitable US government interagency collaboration, or even a public-private partnership arrangement—deserves more attention. Licensing information represents merely the tip of the data iceberg, and globalized supply chains can impose risks beyond disruption, to include infiltration or corruption of supplied products as well. It is relatively easy, for instance, to obfuscate corporate ownership or control relationships—making the supply chain, from a risk-management perspective, opaque in its connective details, even where one has some basic information about the entities involved. Despite the remarkable amount of information available from commercial data aggregators who collect and trade in the so-called digital exhaust of the modern economy, effective analytical tools are not yet widely available, or at scale, to permit transactional linkages to be traced very far backward or forward through any given supply chain. Neither do the existing tools allow one to understand nonobvious relationships between and among entities therein.

Perhaps the most comprehensive private effort at collecting and disseminating global semiconductor supply chain data is by World Semiconductor Trade Statistics (WSTS), an independent body run by an executive committee composed of representatives from semiconductor industry member organizations. WSTS collects monthly data pooled from industry members, checks and aggregates it, and participates in industry conferences to share world industry forecasts. Products include a monthly Blue Book, covering worldwide semiconductor shipments,[64] as well as a Green Book, which aggregates visual representations of the Blue Book data. WSTS also releases an End Use report annually, as well as a biannual industry forecast for the current year and upcoming two years. This information is accessible only to subscribers.[65]

SIA, also in the private sector, has also developed multilevel chip supply chain analytical capabilities that are indispensable to national security, even though they are proprietary.

Some progress is being made on the data and analysis issue; namely, the CHIPS Act allocated $2.3 billion to the Department of Commerce to develop a comprehensive report on the global semiconductor supply chain, including exposure to firms in China as well as US domestic weaknesses. This generous level of funding—almost twenty times the EIA's annual budget for US energy data—should form the core of a US government data fusion and analysis center, operated either directly through an agency or supported by specialized contractors or federally funded research and development centers (FFRDCs). Such a data center should collect and digest the full breadth of relevant information that is now available from commercial data aggregators and market research firms. It would not only acquire such information but employ state-of-the-art data analytics, modeling, and decision-support tools in providing high-quality analysis to inform federal decisions. *The government needs to establish itself as a locus of analytical expertise and understanding on these complex issues*, and it needs to be capable of reaching independent conclusions that are in the public interest. Private sector analysis can then augment this public baseline.

Finally, learning from the resistance that Commerce encountered in its fall 2021 attempts to gather such sensitive commercial data from firms even in friendly nations, special consideration should be given to how such a data center can gain acceptance as mutually beneficial to the international partners on whom its success rests. In that sense, and with an eye toward the United States more effectively navigating what could be a jarring transition to a like-minded, bloc-based trading and technology-sharing pattern, a more appropriate energy data analog may in fact be the multilateral OECD's International Energy Agency (IEA). Similar to the DOE EIA's domestic role, the IEA collects, analyzes, and disseminates detailed energy supply-and-demand statistics from across OECD member nations and volunteering observer nations. Also founded in the throes of the 1970s energy crises to represent the interests of major oil-consuming nations—and with data that is used in service of a broader mission to coordinate oil stockpiles and joint drawdowns across member nations during times of geopolitical disruption—IEA's approach of drawing together like-minded nations around concrete tools to serve mutual interests should be a basis for chip comparison.

Chip Stockpiling and Extended Inventory Management

Could IEA's approach toward oil stockpiling and coordinated drawdown be applied to mitigate sharp dislocations in semiconductor supply chains, too? A condition of membership in the IEA is that countries hold a strategic reserve of oil equivalent of ninety days of net imports, both to reduce actual economic and price impacts caused by supply disruption and to reduce the potential geopolitical leverage of suppliers or other actors who might wish to disrupt energy supply chains.

A combination of public and private chip stockpiles that could create a buffer against one of the most frightening and damaging supply chain risks conceivable—a blockade, war, or natural disaster disrupting supply from a key US partner such as Taiwan—is a model that could improve global semiconductor supply chain resiliency. Even so, there are complicating considerations that suggest a more nuanced approach may be needed.

The first complication is the practical challenge in stockpiling sophisticated, high-end semiconductors in advance of a loss of access. To the degree that such cutting-edge chips come only from Taiwan's TSMC and would be rendered unavailable by conflict, such chips would indeed disappear from the supply chain with the outbreak of hostilities or a natural disaster. But such chips would also be quite expensive to stockpile, given both their per-unit market price and the fact that their value reflects their novelty—stockpiling last year's best logic chips simply ensures depreciation (and, at best, access to last year's technology during a time of conflict).

A more reasonable stockpiling goal, which could keep critical electronic systems functioning in the event of severe supply chain disruption, would therefore focus on more broadly commoditized legacy chip designs. Even this approach, however, has shortcomings. Strategic stockpiles for crude oil work well because the product has a long shelf life and is not very specialized. But the semiconductor industry is highly diverse. A single chip firm such as Texas Instruments alone produces as many as eighteen thousand types of chips, with upward of two hundred thousand to three hundred thousand product lines being produced at any one time across the industry. It is unclear (but deserving of further study) how useful even the inclusion of the top fifty types of chips within a strategic stockpile would be. Stockpiling may be more feasible for memory chips than for logic chips, since the memory chip industry is more organized around commodity chips from interchangeable suppliers all meeting standard specifications (see chapter 6). Of course, this reality also makes it less likely that the whole memory chip supply chain could be severed.

Moreover, these ideas say nothing of the logistical challenges of operating such a stockpile, particularly if it were managed by a nonexpert public sector entity. By comparison, consider how even the US stockpile for personal protective and common medical equipment—which Congress established near the end of the George W. Bush administration in preparation for pandemics—was poorly sustained and barely replenished over time as other political and budgetary priorities arose.

All these impediments, however, do not mean that buffering chip supply chains is impossible.

For example, *"lifetime buys" of commercial components in critical systems* have long been a facet of the aviation and aerospace industry, which faces problems of replacement part obsolescence and unavailability within the functional lifetime of an aircraft.[66] Typically, lifetime buys of replacement parts are a reactive step taken to stockpile parts once a particular component has already been slated to be discontinued. Doing so more proactively for semiconductor components, however, might be a prudent step given our reliance on complex global supply chains, despite the potential cost or performance trade-offs of doing so. For example, when the US Department of Defense (DoD) purchases weapons systems and other military electronics, it has begun to procure in advance some chipsets on a "lifetime of the system" basis. DoD planning in this regard is likely still incomplete, for it is generally based upon anticipated peacetime service life rather than surge demands that might be required in wartime (i.e., in repeatedly replenishing the US arsenal of precision-guided missiles or other munitions, existing peacetime-level stocks will very quickly be expended once the shooting starts, as in Ukraine). Nevertheless, proactive stockpiling is a principle that should be broadly applied for DoD weapons platforms. The feasibility of an up-front lifetime chip procurement approach should be investigated for other security and critical infrastructure needs as well, such as communications systems and the electric grid.

The second complication is the value of leveraging the latent knowledge of the private sector. While the US government has no experience in managing semiconductor or semiconductor input inventories, chip firms do, as part of their normal operations. Their incentives, of course, are to keep such inventories to a minimum to reduce carrying costs. The COVID-19 pandemic, however, revealed that inventory-light just-in-time manufacturing and distribution models can be quite fragile during times of systematic market disruption, with negative consequences for both the private and public sectors.[67] Recognizing the public interest in preventing such problems with semiconductors, *the US government should therefore encourage a private sector strategy of extended inventory management by creating a new tax credit on semiconductor inventories exceeding some normal duration of time*—e.g., a 25 percent credit on inventories exceeding forty-five days—for chip-consuming and -integrating firms in key sectors such as automotive, aerospace, defense, machinery, and electronics. This strategy is a way to progress toward the goal of creating a supply chain buffer that would increase decision time in the teeth of a severe global disruption, and that would do this in a scalable way, without having to develop new government capabilities or heavy-handed interventions.

Beyond purely private inventory management, we believe there are other novel ways to combine private sector supply chain expertise with a broader public resiliency purpose. While a government-only stockpile would likely fail, some have suggested instead *a limited "smart" buffer that would be run as a public-private partnership*. A private operator, independent or perhaps through an FFRDC under contract, would regularly buy and sell volumes of commonly traded chips under normal market conditions—that is, a chip exchange, whose inventory at the scale of a few hundred million dollars would remain property of the US government until sold. Day to day, such an exchange could provide some liquidity within a volatile private market and provide a return to the operator through arbitrage or management fees. But during severe supply chain crises, the inventory in place would flip to government needs such as defense or critical infrastructure. As this proposal would be much more sophisticated than the public stockpiles or exchanges that are operated for other commodities today, such as for oil or sugar, its dynamics within the evolving semiconductor market deserve further analysis.

A final consideration might be *preplanning for allocation and potential chip rationing during a significant supply chain upheaval*. On the one hand, the government could simply not assume such a responsibility on account of lack of knowledge and expertise. On the other hand, in past times of duress, US government bodies have invoked emergency authorities and become involved in the production and distribution of scarce goods that otherwise should remain the province of the private sector—with mixed results. With that history in mind, it would surely be better, in extremis, to turn to a plan carefully drawn up ahead of time on the basis of solid data, sophisticated modeling, and careful planning, than it would be to make such decisions on the fly in a crisis through ad hoc improvisation and guesswork under pressure. A basic prioritization framework should seek to be predictable, administrable, and defensible. Defense and national security applications (e.g., munition replenishment and the replacement of military and naval assets, sensors, and communications systems subject to combat attrition) would presumably be at the top of this chip-allocation priority list, followed by the needs of the civilian economy, such as civilian critical infrastructure systems, emergency and critical health care facilities, aviation safety, and cybersecurity functions. A directive to critical systems integrators to "know your supplier" (plus two or three levels of dependencies beyond) would be a place to start gathering data for such an effort, and would itself be a step of considerable value in light of the ways in which supply chain derisking has moved into the spotlight. It is also essential that our leaders begin a high-level national discussion of just what US national security chip-allocation priorities should actually be in a crisis: dialogue and stakeholder engagement on such topics is best begun before the need actually arises.

In sum, there are several medium-term ways in which the United States can increase the likelihood of commercial success of its current efforts to onshore an augmented share of its chip supply chain, while also taking other steps to mitigate the risk of what is sure to be a continued reliance on friendly partners abroad. Here, our specific relationships with Taiwan and China bear closer examination, as the chapters that follow show.

But with some key semiconductor-related funding and tax measures already in place in the United States, it should be possible to look back in ten years and see concrete progress along both dimensions of onshoring and supply chain risk mitigation, for it is against these two imperatives that today's major policy initiatives such as the CHIPS Act will be evaluated. Demonstrating success will be important not just for semiconductor security, but also as a responsibility to show American taxpayers what they have bought through these emergent yet unconventional public-private policy efforts undertaken in the name of national security. These efforts must be implemented with temperance and in faith in the intentions of the drafters. Securing semiconductor supply chains will not be achieved through one-off legislation. The intersection of the semiconductor business and national security interests is, as former secretary of state George Shultz would observe, not a solvable problem—but rather a "work-at" problem. And there are other critical technologies beyond semiconductors that may need to be worked at in the future, too. So much rests on the execution of today's first legislative steps.

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17. Hideki Tomoshige and Benjamin Glanz, "What Environmental Regulations Mean for Fab Construction," CSIS, July 2022.
18. NEPA requires federal agencies to consider the environmental consequences of proposed actions and inform the public about their decision making. The three levels of environmental analysis possible under NEPA include (1) categorical exclusions (as proposed by individual agencies for routine actions, in

consultation with the White House Council on Environmental Quality; not currently applicable to semiconductor fabs); (2) an environmental assessment (requiring roughly eighteen months to consider an overview of potential environmental impacts, often resulting in some degree of required mitigation or monitoring); or (3) a full environmental impact statement (which includes a detail reporting and public review process and can take many years to complete along uncertain timelines).

19. US EPA, "FAST-41 Coordination—Fixing America's Surface Transportation (FAST) Act," last updated September 27, 2022.
20. US Department of Homeland Security, "Portman, Hagerty, King File Bipartisan Amendment to NDAA to Improve Permitting Process for Key Technologies Impacting National Security," November 2021.
21. The White House, "FACT SHEET: CHIPS and Science Act Will Lower Costs, Create Jobs, Strengthen Supply Chains, and Counter China," August 9, 2022.
22. The White House, "The Biden-Harris Permitting Action Plan to Rebuild America's Infrastructure, Accelerate the Clean Energy Transition, Revitalize Communities, and Create Jobs," accessed May 16, 2023.
23. VerWey, *No Permits, No Fabs*, 20.
24. US Chamber of Commerce, "US Chamber Comments on the Department of Commerce Strong Domestic Semiconductor Industry RFI," March 2022.
25. Phillip Singerman, Sujai Shivakumar, Gregory Arcuri, and Hideki Tomoshige, "Streamlining the Permitting Process for Fab Construction," CSIS, August 29, 2022.
26. VerWey, *No Permits, No Fabs*, 18.
27. McKinsey & Company, "Sustainability in Semiconductor Operations: Toward Net-Zero Production," May 17, 2022.
28. The Act appropriates $5 million to the EPA until September 30, 2031, "to support enhanced standardization and transparency of corporate climate action commitments and plans to reduce greenhouse gas emissions." Matt Hamblen, "Chips Fabs Face EPA Review of Their Emission Targets in Budget Bill," Fierce Electronics, August 11, 2022.
29. US EPA, "Per- and Polyfluoroalkyl Substances (PFAS): Proposed PFAS National Primary Drinking Water Regulation," last updated May 9, 2023.
30. In a November 2022 Economic Innovation Group survey of US voters, 66 percent of respondents said that the immigration system needs major changes or a complete overhaul (including 81 percent of Republicans and 57 percent of Democrats). Kenneth Megan and Adam Ozimek, "US Perspectives on Skilled Immigration: Results from EIG's National Voter Survey," Economic Innovation Group, November 14, 2022.
31. Will Hunt and Remco Zwetsloot, "The Chipmakers: US Strengths and Priorities for the High-End Semiconductor Workforce," CSET, September 2020.

32. These fields include bioenergy, human-centered technology design, cloud computing, climate and geoscience, earth systems science, and so forth.
33. The same 2022 Economic Innovation Group survey reported including 60 percent of Republicans, 72 percent of Independents, and 83 percent of Democrats favoring more skilled immigration.
34. The bill's only educational provision was listed as "Developing and deploying educational and skills training curricula needed to support the industry sector and ensure the US can build and maintain a trusted and predictable talent pipeline."
35. It directed, for example, the secretaries of interior and labor to conduct studies to design educational programs at the undergraduate and graduate levels to support critical mineral supply chains, including grants for faculty positions at institutes of higher learning.
36. US Congress, Space, Science and Technology Committee, *H.R. 4521, United States Innovation and Competition Act of 2021*, 117th Congress, 2021–2022.
37. Commerce Secretary Gina Raimondo suggested that implementation of CHIPS and Science Act of 2022 subsidies would come with "strings attached," and House Speaker Nancy Pelosi told reporters, "What's really important . . . is that there would be guardrails to ensure that chip investments benefit US workers, not foreign companies." For construction of manufacturing facilities themselves under the Act, Davis-Bacon prevailing wage requirements will apply. See Jeremy Dillon, "Congress Nears Passage of Innovation, Research Bill," E&E News, July 25, 2022.
38. As a point of reference on the relative compositions of needed workers, TSMC reported that of its fifty-seven thousand employees in 2020, about six thousand were "managers," twenty-eight thousand were "professionals," five thousand were "assistants," and eighteen thousand were "technicians." Professionals and managers generally hold master's degrees or above. See TSMC, *2020 Corporate Sustainability Report*, 2021.
39. Refundable income tax credits equal the lesser of 10 percent of a total qualified investment, $20,000 per net new job at a facility for investments less than $2 billion, $30,000 per net new job for investments over $2 billion, or $30 million per taxpaying firm per year. Arizona Commerce Authority, "Qualified Facility," accessed May 16, 2023.
40. Arizona Commerce Authority, *Qualified Facility Tax Credit Program: Calendar Year 2021 Annual Report*, April 29, 2022.
41. Compiled from Annual Reports from 2013 to 2021, as available here: Arizona Commerce Authority, "Qualified Facility," accessed May 16, 2023.
42. Arizona House Bill 2321, *Qualified Facilities*, Fifty-Fifth Legislature, 2021.
43. The expansion was backed by the Arizona Commerce Authority, with the president and CEO, Sandra Watson, testifying before the Senate Appropriations

Committee that HB 2321 would enhance the state's competitiveness. At the same time, the bill was criticized by the American Conservative Union (ACU). In the ACU Foundation's 2021 ratings of Arizona, QFTC, and in particular HB 2321, were criticized as providing "competitive advantage to select industries and businesses while shifting tax burdens to other taxpayers not favored by government." See the American Conservative Union Foundation Center for Legislative Accountability, *Ratings of Arizona 2021*, 13, 24.

44. Samsung, "Samsung's $17 Billion Investment in a New Facility Will Boost Production of Advanced Semiconductors," press release, November 24, 2021.
45. Austin Chamber, "Property Tax," 2023.
46. "The Texas Enterprise Fund (TEF) awards 'deal-closing' grants to companies considering a new project for which one Texas site is competing with other out-of-state sites. The fund serves as a performance-based financial incentive for those companies whose projects would contribute significant capital investment and new employment opportunities to the state's economy." Awards tend to be tied to expected job creation levels. See Texas Economic Development, "Texas Enterprise Fund," 2023.
47. Office of the Texas Governor, "Governor Abbott Announces New $17 Billion Samsung Manufacturing Facility in Taylor," press release, November 23, 2021.
48. "Incentive Package to Lure Samsung to Taylor Is the Biggest in Texas History," *The Dallas Morning News*, December 29, 2021.
49. Office of the Texas Governor, "Governor Abbott Announces Texas Instruments' Potential $30 Billion Investment in Sherman," press release, November 17, 2021.
50. Brad Johnson, "Texas Instruments Plans $30 Billion Investment in Sherman Semiconductor Facility," *The Texan*, November 17, 2021.
51. See, for example, Bethany Blankley, "Group Calls on Governor, Legislature to End Texas Enterprise Fund, Cut Taxes Instead," The Center Square: Texas, February 2, 2021.
52. Gov. DeWine's statement: Mike DeWine, Governor of Ohio, "Governor DeWine Highlights Historic Investments in Capital Budget Bill," June 14, 2022.
53. Ohio Legislative Commission, Ohio HB 687, *Ohio Revised Code—Grants to Foster Job Creation*, Section 122.17, div. (A)(11)(a)(ii), 2.
54. Intel, "Intel Announces Next US Site with Landmark Investment in Ohio," press release, January 21, 2022.
55. In Cato's 2021 ranking, the five states with the highest economic freedom scores were (from high to low) Florida, Tennessee, New Hampshire, South Dakota, and Idaho. The five states with the lowest economic freedom scores were (from low to high) New York, Hawaii, California, Oregon, and New Jersey. See William Ruger and Jason Sorens, *Freedom in the 50 States*, 6th ed. (Washington, DC: Cato Institute, 2021), 36.

56. Lee Ohanian and Joseph Vranich, "Why Company Headquarters Are Leaving California in Unprecedented Numbers," The Hoover Institution Economics Working Paper 21117, September 2022.
57. For example, annual average nonfarm employment has grown at a higher rate of increase than total housing units and permits in the San Francisco–Oakland–Berkeley metropolitan area. This problem persists in New York City too, where jobs grew much faster than housing stock over the same period after the Great Recession. See Eric Kober, "The Bay Area: The Land of Many Jobs and Too Few Homes," Manhattan Institute, March 25, 2022; and Emily Badger and Quoctrung Bui, "Cities Start to Question an American Ideal: A House with a Garden on Every Block," *New York Times*, June 18, 2019.
58. Ethan Varian, "Governor Newsom is Blasting CEQA: What Is It and Why Does It Matter?," *The Mercury News*, March 6, 2023.
59. San Jose, California, home to many leading US semiconductor firms, has 94 percent of its residential land zoned for detached single-family homes. This compares to Los Angeles at 75 percent and Seattle at 81 percent. The California legislature has passed a variety of bills to address this issue: SB 8 limits local authorities' abilities to block housing projects and limit housing density by downzoning; SB 9 allows construction of up to four units in single-family zones by right; and SB 10 eases upzoning near transit hubs and restricts cities' ability to use the California Environmental Quality Act to block projects.
60. The EIA today has a staff of approximately three hundred employees and a budget of approximately $125 million.
61. Bureau of Industry and Security, Office of Technology Evaluation, US Department of Commerce, "Notice of Request for Public Comments on Risks in the Semiconductor Supply Chain," September 24, 2021.
62. See, for example, Korean industry and government concerns on competitiveness implications as described here: Shin-Young Park, "US Pressures Samsung, Chipmakers to Disclose Key Internal Data," *The Korea Economic Daily*, September 26, 2021.
63. US Department of Commerce, "Results from Semiconductor Supply Chain Request for Information," January 25, 2022.
64. The Blue Book features 205 semiconductor product categories by revenue and 241 product categories by units, 57 categories thereof split by the regions Americas, Europe, Japan, China, and Asia Pacific/All Other. The data collected by WSTS includes but is not limited to total billing by geographic location, regional growth rate, and total growth rate for each product.
65. Beyond WSTS, private consulting firms and investment banks also publish regular statistical updates on the semiconductor industry for investors. Such analysis tends to focus on trends in gross margin and operating profit as opposed to

forecasts and transparency of the supply chain, though firms including Nathan Associates and Gartner do offer private analyses on semiconductor market share and demand and firm inventory levels.

66. See, for example, dynamics as described in Chris Wilkinson, *Obsolescence and Life Cycle Management for Avionics*, Federal Aviation Administration, DOT/FAA/TC-15/33, November 2015.
67. James Timbie, "National Security Supply Chain Resilience," Hoover Institution, National Security Task Force December 2020 Report.

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