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After the CHIPS Act: The Limits of Reshoring and Next Steps for U.S. Semiconductor Policy

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Introduction

The U.S. Congress's recent success in passing the CHIPS and Science Act (informally the CHIPS Act) shows that legislators are united on one point: the United States needs to manufacture more semiconductors at home. This idea gained traction during the worst days of the coronavirus pandemic, when global shortages of semiconductors halted the manufacturing of automobiles, traditional consumer electronics, and other products that use semiconductors, such as household appliances.[1] As demand for these products soared during the pandemic, the world experienced painful price inflation, which amplified the acute geopolitical tensions between the United States and China.[2] U.S. policymakers, already worried that dependence on Taiwan for the most sophisticated semiconductors could imperil national security and economic security, saw an urgent need to act.[3] And together, rising prices and geopolitical competition underscored the need to invest in domestic economic revitalization.

The CHIPS Act's $52.7 billion investment in domestic semiconductor manufacturing (see table 1) aims to fulfill three main objectives: 1) reduce the likelihood that shocks abroad might disrupt the supply of chips, 2) boost American international economic competitiveness and create domestic jobs, and 3) protect semiconductors from being sabotaged in the manufacturing process. This paper argues that the CHIPS Act, by itself, will not fully accomplish any of these goals. The act is a major step forward, but it leaves multiple gaps that require additional government action. In particular:

- Policymakers must ensure that the $39 billion in CHIPS Act subsidies are usefully divided between fabrication and assembly, testing, and packaging (ATP).

- Government and industry must work together to improve awareness of potential bottlenecks in the supply chain, particularly those arising from opaque supply chain management activities led by the private sector.

- The White House and Commerce Department should convene leading scholars to explore how complementary economic policies and initiatives can create opportunity for struggling parts of the domestic labor force.

- The Commerce Department's CHIPS Program Office must ensure that funding for R&D is supporting initiatives that prepare U.S. companies for paradigm changes in semiconductor technology.

- The Commerce Department, Department of Defense, and Office of the Director of National Intelligence should ensure that their efforts to develop criteria for secure and trusted microelectronics incorporate measures to guard the manufacturing process against remote and insider threats.

- The National Institute of Standards and Technology should facilitate a process to develop open semiconductor security standards with major international producers and consumers of semiconductors.

Table 1: Appropriations in the CHIPS and Science Act

	Program	Appropriation
CHIPS for America Fund	Manufacturing Incentives	$39 billion
	R&D	$11 billion
	Other	$2.7 billion
	Total	**$52.7 billion**
Public Wireless Supply Chain Innovation Fund		$1.5 billion

Beyond the specific steps needed to compensate for the limitations of the CHIPS Act, however, U.S. semiconductor policy needs a stronger foundation that:

- is informed by more data,
- aims to achieve measurable targets, and
- incorporates scenario and crisis planning.

Each of these three pillars is critical, and success with one reinforces the others.

To make effective semiconductor policy, the U.S. government must have an accurate understanding of the global semiconductor supply chain, which first requires gathering and analyzing data. The U.S. government should assess the supply chain using a standardized, repeatable method—enabling comparisons over time and robust supply chain monitoring. These activities would help inform concurrent efforts to set targets and plan for crises.

The U.S. government should set clear targets for the semiconductor industry to benchmark its policy efforts. Rather than setting indeterminate goals, the U.S. government should specify its objectives and provide targets. For example, instead of aiming to "reshore semiconductor fabrication to ensure domestic supply," the U.S. government could aim to ensure that production of a specific share (X percent) of military end-use electronics would not be disrupted by a supply shock in East Asia. Setting specific targets for the semiconductor industry will help policymakers measure progress toward their objectives and plan for crises. In the short term, targets would help the CHIPS Program Office determine how much money should be allocated to fabrication and ATP, respectively.

The U.S. government should designate a planning body for semiconductor crises. Based on data gathered about the supply chain and quantitative targets, this organization would run crisis simulations and provide recommendations for further policy action.

Lastly, as the U.S. government constructs these pillars of effective policymaking, it must also navigate a series of three strategic dilemmas. First, to avoid a subsidy race where each country seeks solely to support its own domestic semiconductor industry, the government should strengthen and confront the tensions involved in coordinating with allies. Second, as the government seeks to support well-paying manufacturing jobs, it must grapple with increasing automation and high skill requirements in semiconductor fabrication. Third, to maintain leading-edge fabrication capacity in the United States, Congress will likely need to make subsequent investments, which will require sustaining political support for industrial policies.

The CHIPS Act clearly marks a turning point for American economic policy, and some say the start of a new age of industrial policy. Whether or not such grand pronouncements prove true, American policymakers have a clear opportunity to de-risk the semiconductor supply chain. The choices that U.S. leaders make today in implementing the CHIPS Act will determine whether the country can maintain its innovation leadership in the semiconductor industry over the long term, as well as the security and continuity of the domestic economy during a crisis. These implementation challenges deserve careful consideration and continuous efforts that are commensurate with the stakes. The CHIPS Act was only the first step of what will likely be a long journey.

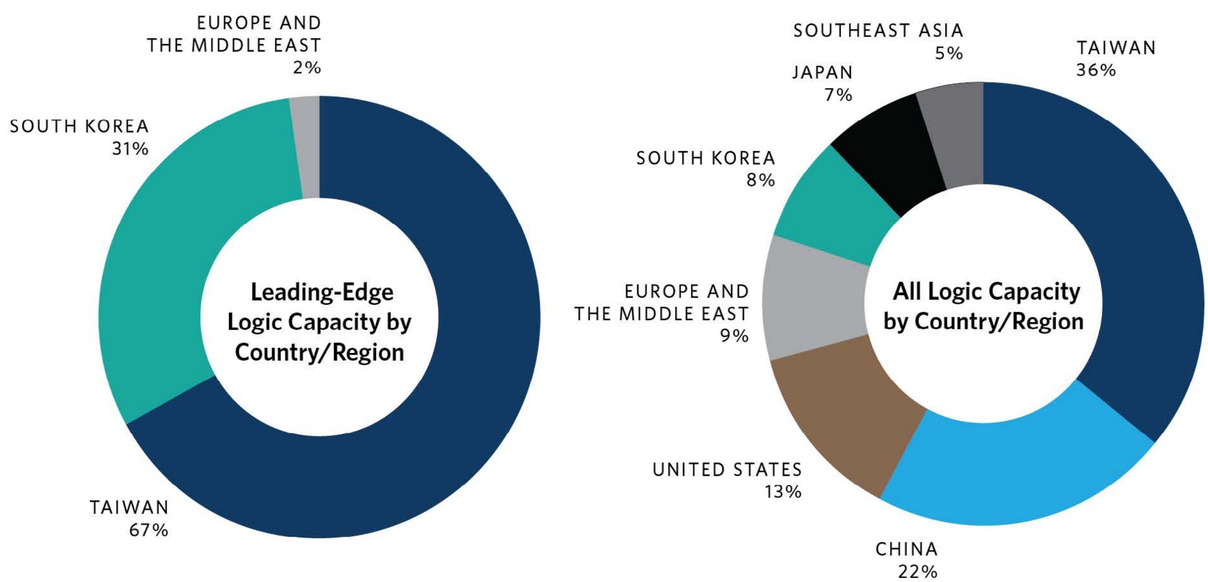
This paper is organized in two sections. The first section analyzes how the CHIPS Act partially fulfills each of the three goals and offers recommendations for addressing the limitations. The second section elaborates on the recommendations and suggests a stronger foundation for U.S. semiconductor policy based on gathering data, setting targets, crisis planning, and charting a clearer strategic direction.

Goals and Limitations of the CHIPS Act

Goal 1: Reducing the Supply Chain's Exposure to Foreign Shocks

The first goal of the CHIPS Act is to diversify the location of semiconductor manufacturing in order to reduce the likelihood that it could be disrupted by turmoil in East Asia. The United States has zero fabrication capacity for leading-edge logic chips (5 nanometers and below), while 67 percent is located in Taiwan and 31 percent in South Korea.[4] Across all logic chips, 73 percent of fabrication capacity is located in East Asia (see figure 1).[5] Concentrating production in any location exposes supply chains to that region's turmoil, whether accidents, natural disasters, or geopolitical and military crises. In East Asia, each of these risk categories poses especially acute threats to the global semiconductor supply chain. For example, Taiwan and Japan (another country seeking to scale up its role in the chip supply chain[6]) sit on the circum-Pacific seismic zone, also known as the "Ring of Fire." As a result, they are particularly exposed to earthquakes and associated natural disasters—risking disruptions.[7]

Figure 1: Semiconductor Logic Fabrication Capacity by Country (2021)



Source: Will Hunt, "Sustaining U.S. Competitiveness in Semiconductor Manufacturing Priorities for CHIPS Act Incentives," Center for Security and Emerging Technology, January 2022, https://cset.georgetown.edu/publication/sustaining-u-s-competitiveness-in-semiconductor-manufacturing/.

Shocks can also come from geostrategic threats. Many policymakers in the United States see the Chinese government's long-term push for more domestic semiconductor manufacturing as an attempt to gain economic leverage.[8] If the world becomes dependent on semiconductors manufactured in China, they reason, the Chinese government could use that dependence as a weapon to achieve other strategic ends.[9] But in the near term, experts worry that the Chinese government might decide to interfere with shipments of semiconductors from East Asia—for example by destroying Taiwan's semiconductor industry in a war or stopping Taiwan's semiconductor exports with an embargo.[10] Recent drills indicate that the Chinese military is at least developing the capabilities for an embargo,[11] and experts write that such limited-force approaches are unpredictable and can rapidly escalate.[12]

The effects of a disruption in Taiwan would be catastrophic for the global economy and would affect more than 50 percent of the world's most advanced chips and the trillions of dollars of commercial activity that depend upon them. Such disruption could also directly affect U.S. national security, denying the United States access to the imported semiconductors that serve as key inputs for military hardware and national security–related R&D. Losing access to these could erode the U.S. military's readiness for armed conflict, slow innovation and research in the national security community, and prevent the United States from supplying its allies and partners with semiconductor-intensive weapons. The war in Ukraine provides a recent example of semiconductors' national security relevance. For example, a single Javelin—the anti-tank weapon that the United States provided to Ukraine—requires at least 250 chips. Ukraine requested hundreds of Javelin systems per day at the outset of the war, but U.S. companies struggled to procure the semiconductors needed to meet the demand.[13] The war has shown how quickly modern militaries must replace their stockpiles of semiconductor-intensive munitions. To prepare for a potential conflict with China, experts have called for the U.S. military to build up its stockpiles and help countries like Taiwan do the same.[14] Acting on these recommendations requires a smoothly functioning, resilient semiconductor supply chain.

Given these risks, the CHIPS Act's investment in building new manufacturing capacity in the United States has some clear longer-term benefits for supply chain resilience. It would create a source of semiconductor supply that is less exposed to the disruptions of potential military conflict and natural disasters in East Asia. It would also expand total global fabrication capacity, a key bottleneck in 2021, when demand for electronics skyrocketed. At that time, fabrication centers (fabs) in Taiwan, South Korea, and elsewhere were being utilized at nearly full capacity and were unable to scale up to meet demand. Expanding total capacity would also reduce the effects of accidents, energy shortages, and other disruptions on the world's supply of chips.

In order to mitigate the effects of foreign shocks on the semiconductor supply chain, however, the Commerce Department's CHIPS Program Office and the cabinet-level CHIPS Implementation Steering Council must pay special attention to two issues.

First, much of the discussion around CHIPS Act investments has focused on fabrication, with relatively little attention given to other stages of the manufacturing process, such as assembly, testing, and packaging. Policymakers often refer to semiconductor "manufacturing" while citing statistics that apply specifically to fabrication.[15] The supply chain is only as secure as its least-secure link, and while the passage of the CHIPS Act is certainly helping diversify the location of fabrication,[16] the world's ATP facilities are also concentrated in China, Taiwan, South Korea, Japan, and a few countries in Southeast Asia.[17] These facilities, like fabrication centers in the region, are exposed to the same wide variety of shocks, any one of which could interfere with the global supply of semiconductors. The CHIPS Act is written to allow for investments along all stages of the manufacturing process, but it does not impose any specific requirements to do so.[18]

The U.S. government's CHIPS implementation strategy contains several nods to both fabrication and ATP, but it seems more concerned with monitoring the types of chips being manufactured at a given facility than the manufacturing substage a given facility represents. From the document, it is unclear whether there exists a process to consider and balance investments in fabrication and ATP. Without adequate attention to this issue, siloing fabrication and ATP allocation could lead the Commerce Department to overfund fabrication and inadequately support ATP. As it distributes CHIPS money, therefore, the Commerce Department must take special care to ensure that all stages of the manufacturing process are adequately funded and that the investments complement one another.

The focus on fabrication has also led policymakers to generally underprioritize the sector's dependence on a huge number of second- and third-tier suppliers around the world. These companies produce industrial machinery, specialty chemicals,[19] crystal growth equipment, and a wide range of other essential products.[20] Japanese firms, for example, are dominant producers of semiconductor materials (24 percent market share) and semiconductor manufacturing equipment (31 percent market share); global dependence on Japanese materials firms is particularly pronounced in wafer production (56 percent market share) and photoresist (90 percent market share).[21] Supply shocks in those industries, whether the result of natural disasters or malicious interference, can also lead to chip shortages. Yet, in the rush to construct new fabs, policymakers have paid relatively less attention to these suppliers.[22] The CHIPS implementation strategy recognizes this problem in a single bullet and notes that facilities for manufacturing these inputs are also eligible for CHIPS funding. However, the strategy does not describe any other measures to monitor or address these potential bottlenecks. As it distributes CHIPS money, the U.S. government should work with semiconductor manufacturing companies to monitor these supply chains and explore whether other measures might be necessary to shore up the risks associated with them.

Second, the CHIPS Act's domestic manufacturing investments do not protect against poor planning by the private sector and crises in adjacent industries. The current chip shortage has highlighted the private sector's role in resisting shocks through demand planning. The automotive sector, for example, suffered acutely from the semiconductor shortage in large part because major carmakers canceled orders for new chips as the pandemic broke out, forecasting lower demand. As a result, when demand began to return to pre-pandemic levels, the carmakers lacked the supply needed to ramp up production, and months-long backlogs for production time at the major foundries meant that new chips would take that much longer to manufacture.[23] Other sectors, such as consumer electronics, did not reduce their orders but were nevertheless surprised by surges in demand due to the increase in "work from home" policies, leading to shortages.[24] Limited global shipping capacity added to the backlog and high costs, leading to further delays in getting chips to manufacturers around the world and getting final products into the hands of customers.[25] The global supply chain is not functioning until chips are in the hands of customers in the form of final products.

Responsibility for these technical processes that get chips into consumers' hands rarely falls to governments. Maintaining adequate inventories and supply of container ships are largely the responsibility of procurement teams at major manufacturing companies and strategy teams at shipping firms respectively. Government agencies can serve as trusted conveners and distributors of timely information on major threats to the supply chain, and they provide surge support to recover from major disruptions. But, when it comes to the day-to-day work that gets chips from fabs to consumer goods—monitoring inventories, keeping track of logistics, and planning for changes in demand and supply—companies are often better positioned. As a result, even if the CHIPS Act succeeds in adding domestic chip-making capacity, damaging shortages could still occur due to poor private-sector planning in a variety of different industries.

To address this issue, the CHIPS implementation strategy encourages companies to enter purchase commitments, which are agreements between companies to purchase a specific number of items in the future at a fixed price.[26] If companies complied, this would smooth demand and help avoid the shortages seen early in the pandemic. But, simply asking companies to make purchase commitments and reduce their flexibility is unlikely to change their behavior. To supplement this request, the U.S. government or a consortium of companies could convene key players to periodically examine forecasts and potential bottlenecks in the supply chain. This approach comes with its own sensitivities—companies are very hesitant to share information about inventory levels, for example—but forcing the key players to explain how they are guarding against various risk scenarios could be a good start.

In short, the CHIPS Act's language and implementation are potentially focused too narrowly. If the law aims to ensure that a baseline level of semiconductor and end-use product manufacturing can continue during a crisis in East Asia, three things must happen.

1. Sufficient fabrication and ATP capacity must be located outside the affected area.
2. Private sector demand planning must be able to quickly account for these shocks.
3. The global logistics chain must be able to absorb and adapt to these changes.

To begin addressing these risks and limitations, policymakers must ensure that the $39 billion in CHIPS Act subsidies are usefully divided between fabrication and ATP. Government and industry must also work together to improve awareness of other potential bottlenecks in the supply chain, particularly those arising from opaque supply chain management activities led by the private sector. The foundation for both these recommendations is a need to collect foundational data and set targets for the U.S. semiconductor sector—discussed in the final section of this paper.

Goal 2: Bolstering Long-Term International Economic Competitiveness and Creating Domestic Jobs

The second goal of the CHIPS Act is to invest heavily in semiconductor manufacturing in order to enhance America's long-term economic competitiveness,[27] as well as to create high-paying domestic jobs by supporting a sector that appears to be increasingly central to the global economy.[28] This argument resonates across the country, given declines in U.S. manufacturing as a share of national production and employment over the past thirty years.[29] Reinforcing the argument are public fears that Chinese firms are rapidly catching up—or even surpassing—their U.S. counterparts in critical technologies.[30] U.S. Senator Todd Young called the CHIPS Act a necessary step to help the United States "not just catch up with but overtake China in these critical areas."[31]

An infusion of cash will certainly help American and allied firms spend more within the United States on the functions they need to increase their share of global semiconductor manufacturing. American semiconductor firms like Intel, for example, will likely be able to grow their share of global fabrication capacity, particularly at advanced process nodes. U.S. firms may also be incentivized to take risks with high expected values, confident that the U.S. government has their back. On aggregate, the new funding will also support semiconductor research and development in the United States, which Edlyn Levine from America's Frontier Fund believes may bolster innovation in downstream industries, including artificial intelligence software and advanced wireless devices.[32] These are all useful if the U.S. government thinks of semiconductors as a strategic resource that it must control, lest other countries gain power and wield influence.

These investments in research and development will also be important as Moore's Law—which predicts that the number of transistors incorporated in a chip will approximately double every twenty-four months—comes to an end. It is becoming increasingly technically difficult (and, therefore, expensive) to cram more transistors into the same space. As a result, the cost of fabs is rising and the number of firms with the expertise and resources to manufacture leading-edge chips is decreasing.[33] Consequently, as the world is demanding more computing power, the semiconductor sector risks stalling out.

Developing future generations of leading-edge chips will likely require thinking beyond the current technology paradigm, which is known as the complementary metal-oxide-semiconductor (CMOS) fabrication process. But the kinds of "coordinating institutions that guided previous technology shifts" operate with vastly diminished budgets or have disappeared entirely. All the while, leading semiconductor firms remain focused on stepwise improvements to CMOS technology.[34] This clear market failure presents an excellent opportunity for government intervention. Experts have argued that a huge proportion of U.S. and global economic growth over the past seventy years was attributable to Moore's Law and the early public investment that made it possible.[35] Government investment in path-breaking semiconductor R&D is once again needed to ensure that the next major technology shift in this sector is driven by U.S. firms, not their Chinese rivals.

On employment, however, some of the rhetoric has been misleading. Policymakers have said that the passage of the CHIPS Act is a major investment in American manufacturing, that the jobs this industry will bring are high-paying, and that they can help ensure that America's manufacturing sector keeps up with other parts of the economy.[36] But this implies that these new semiconductor manufacturing jobs are actually substitutes for the lower-skilled manufacturing jobs lost over recent years to "labor-saving technologies" and outsourcing. Yet, the public lacks a detailed and objective view into the types of jobs modern semiconductor manufacturing would create. Most analysts (and even the White House) buttress their arguments with high-level projections about the law's employment implications from the Semiconductor Industry Association (SIA).[37]

The SIA projects that the semiconductor incentive program will create 1.1 million temporary jobs (for example, those needed to construct fabs), which they estimate will become 523,000 permanent jobs. However, about half of each bucket (49 percent and 48 percent, respectively) is "induced jobs," the result of workers spending their wages on consumer goods and services, such as groceries, utilities, and transportation.[38] These induced jobs provide real economic value, but they will not necessarily bolster U.S. manufacturing employment. Depending on the sector, they are also potentially less likely to endure in the face of automation.

Beyond the induced and indirect jobs, estimates also vary for the number of jobs that CHIPS incentives will directly create in fabs: SIA says about 89,000,[39] while analyst Will Hunt estimates 27,000.[40] Accounting for baseline growth in each occupation, Hunt estimates that only 4,400 (18 percent) of these jobs will go to low-skilled technical workers; the bulk of the jobs will go to engineers and software developers. Hunt also acknowledges that, if anything, "this breakdown likely understates the proportion of skilled engineers required by semiconductor fabs."[41] Furthermore, new jobs for low-skilled technical workers will not all go to U.S. citizens; an estimated 11 percent of the 4,400 new jobs would likely be filled by foreign workers.[42] All told, only a small proportion of permanent fabrication jobs will go to low-skill technical workers who are also U.S. citizens.

The employment argument is also misleading because it implies that the jobs in this sector will be resilient to increasing automation in the manufacturing sector as a whole.[43] Modern semiconductor manufacturing is highly capital-intensive and will likely only grow more so as feature sizes decrease and the production process comes to rely on more precise and intelligent machinery, needing fewer people to operate them.[44] Yet, these longer-term trends do not figure into many analyses of the law.[45]

To be sure, the CHIPS Act does include workforce development programs that aim to train American workers in order to fill some of these jobs, but it is unclear whether these will target the segment of the U.S. labor force most in need of government support. The Commerce Department's CHIPS implementation plan aims to establish up to three new "Manufacturing USA" institutes, which will supply "state-of-the-art facilities and equipment to promote research, propel new products to market, and train the workforce."[46] However, it is unclear that these programs will support the traditional manufacturing workforce. The implementation strategy goes on to state that the new institutes:

> are expected to emphasize virtualization and automation, among other topics. Significant productivity and cost savings can be derived from more widespread adoption of virtualization and simulation of wafer production, and improved automation of manufacturing processes and materials handling and logistics.[47]

In other words, the workforce to which the strategy refers is the high-skilled workforce. If the CHIPS Act's new semiconductor manufacturing jobs cannot be filled by workers displaced from other manufacturing jobs, it is unlikely to be the path to upward mobility that policymakers suggest.

Beyond the CHIPS Act's direct effects on competitiveness and employment, broader questions on these fronts remain. For example, there has been little discussion of whether semiconductor fabrication is better for America's economic competitiveness and domestic employment than other productive enterprises on which the United States could spend its money. Such an analysis of the opportunity cost is essential to understanding whether growing domestic semiconductor manufacturing is the most productive use of U.S. capital.

Within the semiconductor sector, America's strengths already lie in the highest-value segment of the semiconductor supply chain: chip design. Logic design was responsible for 30 percent of semiconductor value-added in 2019, while fabrication was only 19 percent.[48] To support the United States' competitive economic advantage in the semiconductor supply chain while maximizing return on investment, Congress could have focused its investment plan on chip design and R&D.

At the center of these issues is a stark strategic reality: The CHIPS Act is an industrial policy aimed at competing with China by catalyzing innovation in leading-edge chips and manufacturing them at home. As such, it benefits a very different segment of American society than an industrial policy aimed at creating jobs for American workers who are losing ground to the twin tides of globalization and automation. The former can be tailored to offer some benefits to these workers—as CHIPS does—but only so long as large R&D investments in automating the production process do not make progress. When they do, they will eat away at the automatable jobs, and American workers will be back to where they started.

For U.S. leaders considering how to simultaneously compete with China and address the United States' domestic economic challenges, it is crucial to recognize these trade-offs and supplement investments in this capital-intensive industry with initiatives to more directly support American workers through education, the creation of new jobs, and post-employment financial and in-kind support. While adjudicating between specific recommendations on this front is beyond the scope of this paper, there are some economists who have proposed approaches to addressing the widening inequality that results from the lack of "good jobs."[49]

To begin addressing this issue, the White House and Commerce Department should convene leading scholars to explore how complementary economic policies and initiatives can create opportunity for the parts of the domestic labor force that are struggling. In addition, to strengthen the competitiveness of U.S. firms over the coming decades, policymakers and industry leaders must ensure that funding for R&D supports initiatives that prepare U.S. companies for paradigm changes in semiconductor technology.

Goal 3: Reducing the Risk of Sabotage

A third goal of the CHIPS Act is to improve semiconductor security by guarding the manufacturing process against efforts to maliciously alter chips or render them defective. This type of sabotage, either in the manufacturing process or in transit, can have huge consequences for end users.[50] For example, the U.S. government has issued several warnings that hardware originating in certain countries, particularly China, can compromise user data.[51]

While sabotage is not useful or desirable for every adversary, it is certainly possible. One could tamper with semiconductors by altering manufacturing recipes or manipulating the sensors used for performance testing at several stages of production.[52] With the most reputable manufacturers, such as Intel, Taiwan Semiconductor Manufacturing Company (TSMC), and Samsung, the risks of sabotage are relatively lower—given the resources these companies can invest in security and the importance of consumer trust to their business. They might, nevertheless, allow their security practices to atrophy. They could also be attacked by a particularly skilled and determined adversary (for example, a nation-state), against whom even capable security teams would struggle. With less-reputable manufacturers, including and especially those beholden to national governments, the risks increase. Such companies might facilitate sabotage as a willing or coerced partner of a government or influential private entity. And after the manufacturing phase, the chips are transported around the world—where their security becomes the concern of shipping companies and port authorities. If compromised chips find their way into military hardware, enterprise systems, or personal devices, they could fail to perform necessary functions at critical moments and act as a gateway for attackers to steal sensitive data or carry out more destructive attacks. The 2018 Specter and Meltdown vulnerabilities in Intel and AMD chips, while not the result of sabotage, affected millions of people, demonstrating how consequential exploited hardware vulnerabilities can be.[53]

While much is unknown about the nature and scope of state interventions in the supply chain, conditions like geography and national laws make some types of interventions more likely than others. For example, bulk institutionalized sabotage depends in part on a state actor encouraging or turning a blind eye to the activity. Governments necessarily have an easier time carrying out these operations at home, within their own jurisdictions, where national laws favor them and foreign intelligence services have a difficult time operating. Bloomberg controversially alleged, for example, that the Chinese government orchestrated this type of sabotage along production lines in China for server chips produced for the San Jose–based company Supermicro.[54] While the story was heavily disputed and never independently confirmed, many people took it seriously at the time because Beijing might theoretically be capable of such operations within Chinese territory. Following that story and other reporting on hardware vulnerabilities, experts called on the U.S. government to take additional measures to protect against supply chain attacks.[55]

In contrast, abroad, where intelligence and law enforcement services are on the lookout for espionage and sabotage, adversaries might have an easier time turning to smaller-scale approaches to interfering with the fabrication process. They might remotely manipulate specific sensors used to test chips if they can compromise the cybersecurity of manufacturing centers' digital networks. They can also use traditional methods, such as recruiting or paying individuals in positions of authority to conduct espionage and sabotage on their behalf. These are functions that national intelligence services regularly carry out across borders in other contexts.

By virtue of being located in the United States, new CHIPS Act–funded facilities will likely be less vulnerable to bulk-institutionalized sabotage than other similar facilities if China gains a greater share of global manufacturing capacity, but they remain equally exposed to smaller-scale remote or covert attacks. Bulk institutionalized sabotage would be more difficult to conduct without being detected by the U.S. government because these manufacturing facilities would likely be on the radar of U.S. counterintelligence officers. Additionally, U.S. law would give federal agents the authority to investigate these facilities if they suspected threats to national security. But shifting a facility's geographic location does not protect it against remote threats. Any effort to defend against chip sabotage must take seriously cybersecurity and insider threats.

Moreover, if the CHIPS Act remains focused on fabrication, sabotage in the assembly, testing, and packaging phase would remain a real possibility. Once a chip design firm like NVIDIA has finished fabricating at TSMC or Samsung Foundries, they often need to send their chips to another company for ATP. In 2019, according to SIA estimates, at least 38 percent of global ATP value was created in China and another 43 percent was created elsewhere in East Asia.[56] If policymakers are concerned about remote or covert sabotage in the fabrication phase, they should be similarly concerned about the ATP phase. Attacks targeting the fabrication phase, some experts argue, "are high cost and require generating at least one new mask set,[57] an in-depth analysis of the device, and a high degree of expertise."[58] Additionally, they are imprecise, as attackers can rarely be sure that the altered hardware will make its way into specific end-use products. This potentially makes the ATP phase an easier and more attractive target.

Beyond moving the location of production, governments and companies can collaborate to develop shared standards and best practices to improve the security of semiconductor manufacturing. Companies regularly use this approach to counter other, similar hardware integrity challenges without relocating production. They must prevent counterfeit components from being used in final products and ensure that defective products are not unintentionally sold to consumers, all while continuing to manufacture a large share of those components and final goods in China. They also attempt to address this problem using a wide range of trust-building, transparency, and accountability measures in addition to researching new manufacturing techniques and technologies that can better produce trustworthy hardware. Given that it is impossible to be fully confident that a piece of hardware has not been the target of a state intervention, perhaps open standards and these other techniques could help address fears that production in foreign countries is at risk of sabotage.[59]

Simultaneously, U.S. policymakers must recognize that hardware integrity is often in the eye of the beholder. Significant government oversight of and intervention in U.S.-based semiconductor manufacturing risks raising concerns that the United States government could interfere with U.S.-origin chips being shipped around the world. Developing open semiconductor security standards with major producers and consumers of semiconductors, or at least openly communicating any new standards to such a group, could help guard against supply chain attacks while preserving trust in U.S.-origin semiconductors.

The U.S. government's CHIPS Act implementation strategy takes a strong step toward addressing sabotage risks, albeit in general terms. It tasks the CHIPS Program Office, Department of Defense, and Office of the Director of National Intelligence with defining requirements for "secure and assured microelectronics."[60] This new effort should consider drawing on existing programs in the Department of Defense, including:

- the Defense Microelectronics Activity's Trusted Foundry program,[61] which designates "trusted sources" for custom and application-specific semiconductors and

- the Department of Defense Research and Engineering's Trusted and Assured Microelectronics (T&AM) projects, which aim to develop "best practices for secure design, assembly, packaging, and test capabilities" for using off-the-shelf semiconductors in the defense industrial base.[62]

Through T&AM in particular, the Defense Department is grappling with how to ensure a secure supply chain for commercially available semiconductors. It is also reasonable to assume that the new CHIPS Act semiconductor security initiative will lean heavily on promising initiatives in industry and academia to devise best practices for designing secure chips and manufacturing processes.[63]

As these agencies implement the strategy, they should aim to ultimately convert some of their work into open standards that can be updated as the technology and best practices evolve. By creating a process for revisiting and updating these standards as they improve, the U.S. government can ensure that industry security standards remain up to date.

These standards would also benefit from input by U.S. allies and partners who are investing in their own semiconductor manufacturing. Incorporating feedback from allies could help ultimately build an international network of secure, trusted fabs and ATP facilities that could be mobilized and potentially switched between during a crisis without sacrificing security. A recent paper by the National Institutes of Standards and Technology (NIST) describes a strategic opportunity in setting semiconductor manufacturing standards.[64] Standards become more beneficial as they are adopted by more users. Ensuring that NIST involves international partners when it sets standards for microelectronics security standards in coordination could go a long way to realizing these benefits.

In short, changing the location of semiconductor manufacturing will only address a subset of chip sabotage risks. To build a trusted supply chain, policymakers and industry will need to address cross-border threats, including cyber attacks and traditional espionage. Existing U.S. government initiatives, notably some housed at the Defense Department, and industry-developed best practices for trust-building could be brought together to create standards for semiconductor security. Such standards could help mitigate the threat of sabotage while preserving global trust in U.S.-origin hardware.

Next Steps

This paper has made several recommendations that aim to help the U.S. government better address its concerns about the security and resilience of the semiconductor supply chain. It has also attempted to frame the strategic dilemma that confronts efforts to use semiconductor manufacturing as a vehicle for both international competitiveness and domestic employment simultaneously. These recommendations include the following.

- Policymakers must ensure that the $39 billion in CHIPS Act subsidies are usefully divided between fabrication and assembly, testing, and packaging.

- Government and industry must also work together to improve awareness of potential bottlenecks in the supply chain, particularly those arising from opaque supply chain management activities led by the private sector.

- The White House and Commerce Department should convene leading scholars to explore how complementary economic policies and initiatives can create opportunity for struggling parts of the domestic labor force.

- The Commerce Department CHIPS Program Office must ensure that funding for R&D is supporting initiatives that prepare U.S. companies for paradigm changes in semiconductor technology.

- The Commerce Department, Department of Defense, and Office of the Director of National Intelligence should ensure that their efforts to develop criteria for secure and trusted microelectronics incorporate measures to guard the manufacturing process against remote and insider threats.

- The National Institute of Standards and Technology should develop open semiconductor security standards with major international producers and consumers of semiconductors.

However, beginning to act on these recommendations requires a foundation that does not yet appear to exist. This section outlines recommendations on three topics that together constitute the needed foundation. They are

- gathering data,

- setting targets, and

- crisis planning.

Policymakers will also need to navigate three strategic dilemmas:

- aligning domestic and foreign semiconductor policy,

- ensuring opportunities for the domestic labor force, and

- balancing political imperatives.

Strengthening the Foundations of U.S. Semiconductor Policy

Gathering data. The foundations of any large-scale industrial policy ought to be data. Given the complexity of the semiconductor supply chain and trade secrets concerns among major industry players, however, the U.S. government does not have the data needed to identify the most vulnerable parts of the supply chain and precisely direct CHIPS money toward them.[65] Analysts need more insight into the semiconductor supply chain's structure and potential bottlenecks.

Fortunately, some infrastructure for this exists, but it needs to be expanded upon and integrated with the CHIPS implementation process. According to joint statements from the recent U.S.-EU Trade and Technology Council Meeting and the Quad Leaders Meeting, for example, the U.S. government has set up programs with ally and partner governments that aim to identify and provide early warning of supply chain bottlenecks.[66] The data that informs these judgments could likely be used to more precisely identify vulnerabilities (particularly at the second and third-tier supplier levels) and target CHIPS funding accordingly.

Notably, the CHIPS Act itself recognizes the international dimensions of U.S. semiconductor policy. The law appropriates $500 million to establish an International Technology Security and Innovation Fund at the U.S. State Department for a wide range of activities. Some of this money could be used to support international data gathering and supply chain monitoring efforts.[67]

Other proposals would put supply chain monitoring in the Department of Commerce or perhaps in an independent agency. Experts at the Center for a New American Security have suggested that Congress create an assistant secretary position in the Commerce Department, overseeing supply chain and technology security.[68] This new leader and the bureau under their leadership would be responsible for supply chain monitoring, among other functions. This arrangement would utilize the Commerce Department's long-standing ties to industry. Similarly, Chris Miller has proposed placing a lower-level unit in the Commerce Department's International Trade Administration to track technology supply chains.[69] Alternatively, Erica Fuchs has proposed a Critical Technology Analytics Program that would likely operate as a coordinating body between government, academia, and the private sector—operating "beyond the purview of any one federal agency or private firm."[70] Either of these options, if properly resourced and organized, would improve on the status quo, but standing up a new organization will take time.

In the short term, to improve semiconductor supply chain monitoring and vulnerability analysis, the U.S. government should look to the Commerce Department's CHIPS Program Office. The office should contract with trusted firms that already monitor critical supply chains such as the World Semiconductor Trade Statistics program. These services report granular data on production and trade at many nodes along the semiconductor supply chain. Many also design network analysis tools that help manufacturers gain more insight into their second- and third-tier suppliers and potential vulnerabilities. The companies that offer supply chain mapping services, perhaps more so than the manufacturers themselves, have insight into the structure, flow, and bottlenecks in complex supply chains. Working with them can supplement information that the government already gathers from the manufacturers.

Setting targets. With data in hand, the U.S. government needs to set clear targets for the U.S. semiconductor industry. The Commerce Department's CHIPS Act implementation strategy talks about "ensur[ing] long-term leadership in the [semiconductor] sector" and "strengthen[ing] and expand[ing] regional manufacturing and innovation clusters," but it does not set clear, measurable targets.[71] Industrial policy is often a large optimization problem. Governments must invest enough to achieve their goals, but not so much as to be duplicative or inefficient. However, without some targets for which to optimize, it is difficult to make prudent decisions about which CHIPS projects are most worth funding and which new investments are unnecessary. Without targets, it is also difficult for U.S. negotiators to know what to keep and what they can give away when negotiating to avoid subsidy races with allies and partners. Such goals could include:

- to maintain domestic fabrication capacity equal to X percent of global capacity in particular nodes,
- to ensure that production of Y percent of commercial or military end-use electronics can not be disrupted by a supply shock in East Asia,
- to employ Z amount of people in the semiconductor sector, or
- to boost growth in key economic development zones by A percent.

Crucially, this target-setting exercise must not lose sight of the goals of reshoring. In order to make the supply chain more resilient to shocks, U.S. policymakers must clearly identify what types of semiconductors they think are most important and factor these targets into their plans for distributing CHIPS Act money. Supply crises of critical inputs, for example, force governments to manually allocate limited supply to different sectors and firms, as the German government has planned in the event of a possible natural gas shortage this winter.[72] Making those decisions requires a clear understanding of which types of consumption matter most. Yet based on the public record, the government does not appear to have engaged in this sort of planning. Additionally, the U.S. government must explore whether setting targets to mitigate potential bottlenecks in other areas, like the global logistics sector, are needed to help meet these targets.

Crisis planning. Ideally, with targets in hand, the executive branch should run crisis simulations to determine how various threat scenarios impact the supply of semiconductors and U.S. consumption of end-use products, how the U.S. government will respond, and how various CHIPS Act investments help mitigate the risks and facilitate recovery. In the event of a semiconductor crisis, the U.S. government could use the Defense Production Act or other authorities to prioritize national-security specific systems, inputs to key private sector-controlled systems (such as cloud servers), or consumer electronics (like laptops and cars). However, ensuring that U.S. firms and consumers will get the chips they need during a crisis depends on policymakers clearly identifying which functions they seek to preserve.

If policymakers aim to ensure that *U.S. firms* have priority access to domestically fabricated semiconductors during a foreign supply crisis, they will need assurances that the most important firms would have priority for domestic fabrication capacity during a crisis. Otherwise, those firms could still get stuck at the back of the wait list for U.S. fabs.

If policymakers instead aim to prevent a foreign semiconductor supply crunch from causing shortages in end-use products that are *sold to U.S. customers*, the implementation lift is even heavier. As most ATP and product assembly is located in East Asia,[73] semiconductors fabricated in the United States might still need to travel to multiple overseas factories in East Asia for ATP and product manufacturing/assembly before they can be sold as a final product. And after being manufactured, a final product (containing a U.S.-fabricated chip) will not necessarily be sold in the United States.

To ensure availability of supply to American consumers during a crisis, the U.S. government would need to ensure that when Apple, for example, receives a shipment of U.S.-fabricated chips at their iPhone assembly plants in China, the company sends those finished goods to the United States instead of Europe or Asia. Even with greater domestic supply, it won't be easy to ensure that U.S.-fabricated chips are primarily used to satisfy domestic U.S. demand for electronics. Based on the priorities that emerge from "continuity of the economy" (COTE) planning[74]—a planning exercise that prepares the U.S. federal and state governments to help the U.S. economy endure and recover from a major cyber attack—experts and policymakers can test individual risk scenarios and begin to devise ways around the operational barriers to meeting COTE targets.

A scenario planning exercise for a Chinese invasion of Taiwan might conclude, for example, that the United States can maintain semiconductor supply to its defense industrial base by expanding U.S. domestic fabrication capacity and by creating a new capability: "island mode." During an electricity blackout, some power plants can detach from the grid in order to continue supplying critical infrastructure; this is known as island mode. The Medical Area Total Energy Plant (MATEP) in Boston, for example, continues to power hospitals in Boston's Longwood Medical district even when the rest of the grid is not functioning. Similarly, during normal operation, subsidized U.S. fabs would be integrated into the global semiconductor supply chain, but during a crisis, they could be switched to island mode, offering priority capacity to defense customers and switching to domestic packaging services for those orders.

In general, these crisis planning efforts should:

- clearly identify narrow categories of semiconductors that must be protected and prioritized in the event of a crisis;

- review legal authorities to ensure that the U.S. government can require domestic, subsidized fabs to prioritize certain customers (for example, the military, elements of the defense industrial base, and other U.S. firms and/or end users in priority sectors); and

- designate a coordinating/enforcement agency that will work with the fabs, domestic ATP, and end-use customers. This body would be responsible for developing/maintaining an action plan and coordinating with relevant parties in advance, so that the Department of Defense—or the defense industrial base at large—can switch to a clean/domestic chip supply chain during a crisis.

These planning efforts should be carried out by the same organization that will gather and analyze semiconductor supply chain data.

Navigating Three Strategic Dilemmas

Aligning domestic and foreign semiconductor policy. These recommendations point to the need for the domestic and international dimensions of U.S. semiconductor policy to connect with one another, both conceptually and organizationally.

The international playing field has not remained static as Congress deliberated over the CHIPS Act. Already, the sector is adapting to compensate for geopolitical risk and the vulnerabilities exposed by the coronavirus pandemic. TSMC, for example, is building a plant to produce 5-nanometer semiconductors in the United States while simultaneously expanding its production capacity in Taiwan—where its most advanced 3-nanometer semiconductors will be produced—and fielding bids from third countries like India to expand production.[75] Government subsidies, loan guarantees, and tax credits are behind much of this rearrangement, and the chipmakers themselves have said that subsidies are the single most important factor in deciding where they will stand up new fabrication capacity. The result is, potentially, a subsidy race that sees allies overspend to secure the highest bid, while duplicating some production. In short, with other countries in the game, it could get expensive to address supply chain issues by reshoring production.

A subsidy race among allies is wasteful, especially at a time when U.S. policymakers are contemplating strategic investments in many sectors. But it is in the interests of major semiconductor manufacturers to play up supply chain fears in national capitals in order to drive up subsidies. To mitigate the severity of this race, policymakers could use "minilateral" forums like the U.S.-EU Trade and Technology Council and the "Chips 4" alliance,[76] which includes the United States, South Korea, Japan, and Taiwan. In these settings, national governments could develop shared priorities—identifying which chips are most important to protect against shocks, sabotage, and nonallied competition—and agree on joint investment plans that offer politically defensible benefits to all involved. This approach would draw on the data collection and planning efforts described in previous sections. It would distribute the costs of building semiconductor supply chain resilience. This approach would also help deepen economic coordination among the allies and partners, which is needed to buttress the United States' emerging economic and technological competition with China. Such processes have begun but have thus far only resulted in commitments to discuss the issues in principle. A stronger political commitment to the discussions and clear targets for the negotiations could help build momentum.

Similar balancing challenges manifest when considering how to align domestic and foreign semiconductor policy during a crisis. Focusing solely on preserving domestic supply during a crisis could lead the U.S. government to channel an outsized share of U.S. production to domestic consumers at the expense of allied economies. Doing so might ensure semiconductor supply to U.S. customers in the short term but ultimately prolong the crisis and do greater harm to the global economy. More research and international dialogues are needed to explore and mitigate these risk scenarios.

Mutual understanding could form the basis for more robust agreements in larger fora on how to distribute the semiconductor value chain among a select group of likeminded countries. Some of this analytical work has already been done outside of government.[77] These fora could also help develop shared approaches to the other risks that the CHIPS Act does not sufficiently address, such as monitoring and sharing data about the semiconductor supply chain, addressing risks in the global logistics sector, and setting common security standards for semiconductor manufacturing operations.

Ensuring opportunities for the domestic labor force. The tensions between advanced semiconductor manufacturing and boosting domestic low-skill employment will only grow more acute as the semiconductor sector begins to rely on more automation and advanced machinery to produce ever-smaller chips and ultimately moves beyond the current CMOS technology paradigm.

To ensure that this investment in American competitiveness does not undermine other efforts to support the workers most vulnerable to technological and policy changes in the new economy, policymakers should urgently invest in and act upon research that offers ways to increase the supply of "good jobs" and provides for a pathway to economic upliftment as the manufacturing sector ceases to serve that function. Already, economists and political scientists are exploring this problem.[78] The Commerce Department and the White House could begin by convening these and other leading scholars to hear their recommendations and begin identifying ways to integrate their recommendations into policymaking in the semiconductor and other sectors.

While it is well beyond the scope of this paper to adjudicate between their recommendations, it is nevertheless clear that semiconductor policy ought to be devised in conjunction with cutting-edge research on how to better support the American labor market. The sustainability of industrial policies aimed at bolstering American international competitiveness depends on whether voters individually derive value from them. A strategy for competitiveness that comes at the expense of their well-being is unlikely to endure.

Balancing political imperatives. Furthermore, if policymakers aim to maintain leading-edge capacity in the United States, they may need to make additional investments every few years to keep up with the constant grind of technological progress. TSMC and Samsung's 3-nanometer processes are currently at the leading edge, but TSMC aims to begin high-volume production of its next generation N2 process in the second half of 2025.[79] Others have recommended allocating CHIPS Act funding to support domestic fabs at those two process nodes, but doing so would leave insufficient resources to incentivize domestic production when the industry moves to the next leading-edge node.[80] To maintain leading-edge capacity in the United States, Congress might need to appropriate additional funds to attract future production, and legislators will need to persist with this strategy, potentially against political headwinds. The chip industry famously undergoes booms and busts, where excess capacity goes unused and new chip designs make old manufacturing facilities obsolete.

When demand cools, economic conditions worsen or technology paradigms change, future rounds of subsidies to some of the world's most profitable companies will likely face strident opposition. Indeed, the CHIPS Act itself attracted some.[81]

Other dimensions of semiconductor policy could also face political headwinds. For example, individual members of Congress and voters may take issue with how the executive branch prioritizes their region and weighs its comparative advantage relative to other priorities. As the administration negotiates with foreign countries about how to avoid subsidy races and distribute stages of the semiconductor supply chain internationally, political considerations will need to be front of mind.

Conclusion

As America's conscious foray into industrial policy, the CHIPS Act is an important political breakthrough and a potentially transformative piece of legislation. It highlighted that the United States, despite its dysfunction, is capable of mobilizing large amounts of money to meet strategic challenges. But the CHIPS Act will only partially address the most dangerous risks to the semiconductor supply chain. More fully addressing them will require specific actions, such as carefully monitoring the balance between new fabrication and packaging capacity. To more fully close the gaps, the CHIPS Implementation Steering Council, the Commerce Department, and others must strengthen the foundations of U.S. semiconductor policy by gathering and analyzing supply chain data, setting measurable targets for CHIPS Act investments, and conducting planning exercises that simulate a potential semiconductor supply chain crisis.

Admittedly, this paper does not resolve the three strategic dilemmas it raises: how to align domestic and foreign semiconductor policy, how to ensure this industrial policy or its complementary initiatives make good on their promises to the domestic labor force, and how to navigate the political imperatives that will constrain future government action. As Commerce Secretary Gina Raimondo responded when presented with one of those dilemmas at a recent public event on industrial policy, "that's a real question."[82] Answering these questions requires further research, consultations with a wide range of experts, and ultimately, courageous political leadership.

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Notes

1 Sam Shead, "The Global Chip Shortage Is Starting to Have Major Real-World Consequences," CNBC, May 7, 2021, https://www.cnbc.com/2021/05/07/chip-shortage-is-starting-to-have-major-real-world-consequences.html.

2 Gina M. Raimondo, "Secretary Raimondo Announces Results of Request for Information on Semiconductor Supply Chain," U.S. Department of Commerce, January 25, 2022, https://www.commerce.gov/news/blog/2022/01/secretary-raimondo-announces-results-request-information-semiconductor-supply.

3 Iain Marlow, "US Dependence on Taiwan Chips Is 'Untenable,' Raimondo Says," *Bloomberg*, July 21, 2022, https://www.bloomberg.com/news/articles/2022-07-22/us-dependence-on-taiwan-chips-is-untenable-raimondo-says.

4 Will Hunt, "Sustaining U.S. Competitiveness in Semiconductor Manufacturing Priorities for CHIPS Act Incentives," Center for Security and Emerging Technology, January 2022, table 5, https://cset.georgetown.edu/publication/sustaining-u-s-competitiveness-in-semiconductor-manufacturing.

5 Ibid.

6 Yuki Furukawa and Takashi Mochizuki, "Japan Approves $6.8 Billion Boost for Domestic Chip Industry," *Bloomberg*, November 26, 2021, https://www.bloomberg.com/news/articles/2021-11-26/japan-approves-6-8-billion-boost-for-domestic-chip-industry.

7 Adrienne Downey, "Recent Earthquakes Highlight Risk To Semiconductor Manufacturing Sites," Semiconductor Engineering, July 24, 2019, https://semiengineering.com/recent-earthquakes-highlight-risk-to-semiconductor-manufacturing-sites.

8 Dan Strumpf and Liza Lin, "China Chases Chip-Factory Dominance—and Global Clout," *Wall Street Journal*, July 24, 2022, https://www.wsj.com/articles/china-bets-big-on-basic-chips-in-self-sufficiency-push-11658660402.

9 Joe Wallace and Georgi Kantchev, "Russia Slashes Gas Flows, Aiming Economic Weapon at Europe," *Wall Street Journal*, June 16, 2022, https://www.wsj.com/articles/russia-slashes-gas-flows-aiming-economic-weapon-at-europe-11655393254.

10 Becca Wasser, Martijn Rasser, and Hannah Kelley, "When the Chips Are Down," Center for a New American Security, January 27, 2022, https://www.cnas.org/publications/reports/when-the-chips-are-down.

11 Tiffany May and Mike Ives, "China's Military Drills and Other Tensions With Taiwan, Explained," *New York Times*, August 8, 2022, https://www.nytimes.com/article/china-taiwan-explained.html.

12 Michael E. O'Hanlon, "Can China Take Taiwan? Why No One Really Knows.," Brookings Institution, August 2022, https://www.brookings.edu/research/can-china-take-taiwan-why-no-one-really-knows.

13 Yuka Hayashi, "Chip Shortage Limits U.S.'s Ability to Supply Weapons to Ukraine, Commerce Secretary Says," *Wall Street Journal*, April 27, 2022, https://www.wsj.com/livecoverage/russia-ukraine-latest-news-2022-04-27/card/chip-shortage-limits-u-s-s-ability-to-supply-weapons-to-ukraine-commerce-secretary-says-pCWERV2HkSPzTdQG4CRI.

14 Hal Brands, "Ukraine War Shows the US Military Isn't Ready for War With China," *Bloomberg*, September 18, 2022, https://www.bloomberg.com/opinion/articles/2022-09-18/ukraine-war-shows-the-us-military-isn-t-ready-for-war-with-china; and Blake Herzinger, "Taiwan Needs Weapons for Day 1 of a Chinese Invasion," *Foreign Policy*, September 8, 2022, https://foreignpolicy.com/2022/09/08/taiwan-needs-weapons-for-day-1-of-a-chinese-invasion.

15 Amy B. Wang and Mike DeBonis, "Senate Passes Bipartisan Bill to Subsidize U.S.-Made Semiconductor Chips," *Washington Post*, July 27, 2022, https://www.washingtonpost.com/politics/2022/07/27/senate-chips-funding-bill-pass.

16 Anton Shilov, "U.S. Semiconductor Renaissance: All the Upcoming Fabs," Tom's Hardware, August 29, 2022, https://www.tomshardware.com/news/new-us-fabs-everything-we-know.

17 Semiconductor Industry Association and Boston Consulting Group, "Strengthening the Global Semiconductor Supply Chain in an Uncertain Era," Semiconductor Industry Association, April 2021, 5, exhibit 1, https://www.semiconductors.org/strengthening-the-global-semiconductor-supply-chain-in-an-uncertain-era; and
Saif M. Khan, "The Semiconductor Supply Chain: Assessing National Competitiveness," Center for Security and Emerging Technology, January 2021, 24, figure 12, https://cset.georgetown.edu/publication/the-semiconductor-supply-chain.

18 "Biden Administration Releases Implementation Strategy for $50 Billion CHIPS for America program," U.S. Department of Commerce, September 6, 2022, https://www.commerce.gov/news/press-releases/2022/09/biden-administration-releases-implementation-strategy-50-billion-chips.

19 "Electronic Chemicals: Semiconductors, Silicon and IC Process Chemicals," IHS Markit, December 2020, https://ihsmarkit.com/products/electronic-chemicals-semiconductors-chemicals-scup.html.

20 For a sample of the wide range of associated industries and companies, see this list: http://www.semiconductor-today.com/suppliers.shtml.

21 Saif M. Khan, "The Semiconductor Supply Chain: Assessing National Competitiveness."

22 Cheng Ting-Fang and Lauly Li, "The Resilience Myth: Fatal Flaws in the Push to Secure Chip Supply Chains," *Financial Times*, August 4, 2022, https://www.ft.com/content/f76534bf-b501-4cbf-9a46-80be9feb670c.

23 "Supply Chain Issues and Autos: When Will the Chip Shortage End?," JP Morgan, August 11, 2022, https://www.jpmorgan.com/insights/research/supply-chain-chip-shortage.

24 Shine Jacob, "PC, Laptop Demand on the Rise but Chip Shortage a Cause of Concern, Says HP," *Business Standard*, January 24, 2022, https://www.business-standard.com/article/companies/pc-laptop-demand-on-the-rise-but-chip-shortage-a-cause-of-concern-says-hp-122012001176_1.html.

25 Enda Curran, "Supply Snarls Disrupt Chips and Ships as Higher Costs Abound," *Bloomberg*, March 17, 2021, https://www.bloomberg.com/news/newsletters/2021-03-17/supply-chain-latest-chip-and-ship-delays-fan-inflation-concerns.

26 Harold Averkamp, "Purchase Commitments Definition," Accounting Coach, https://www.accountingcoach.com/terms/P/purchase-commitments.

27 "Competitiveness" is a malleable term. Its definition is contested by scholars and international institutions. At issue is whether a nation's economic competitiveness is defined by its ability to increase standards of living for its inhabitants (as the Organisation for Economic Co-operation and Development says) or whether it is

exclusively a measure of "its ability to supply increasing aggregate demand and maintain exports." For the purposes of this paper, we use the term "competitiveness" narrowly to refer to the productivity and profitability of firms, which can be in excess of (and even at the expense of) benefits enjoyed by a country's workforce. See "Regional Competitiveness," Organisation for Economic Co-operation and Development, accessed November 10, 2022, https://www.oecd.org/cfe/regionaldevelopment/regionalcompetitiveness.htm; and Hanna Shvindina, "Economic Competitiveness: An Overview of Multilevel Concept" in Walter Leal Filho, Anabela Marisa Azul, Luciana Brandli, Pinar Gökçin özuyar, and Tony Wall (eds.), *Responsible Consumption and Production*, Encyclopedia of the UN Sustainable Development Goals (Springer, Cham, 2020) https://doi.org/10.1007/978-3-319-95726-5_63.For simplicity, we discuss international market share and domestic employment separately—recognizing that they reinforce one another.

28 Stephen Ezell, "Why America Needs Semiconductor Legislation to Bolster Its Economic and National Security," *Information Technology & Innovation Foundation*, January 24, 2022, https://itif.org/publications/2022/01/24/why-america-needs-semiconductor-legislation-bolster-its-economic-and.

29 Yukon Huang and Jacob Feldgoise, "What Both US and China Get Wrong on Economic Policy and Trade Negotiations," *South China Morning Post*, December 6, 2021, https://www.scmp.com/comment/opinion/article/3158308/what-both-us-and-china-get-wrong-economic-policy-and-trade; and Adam S. Posen, "The Interconnected Economy: The Effects of Globalization on US Economic Disparity," Peterson Institute for International Economics, September 28, 2021, https://www.piie.com/commentary/testimonies/interconnected-economy-effects-globalization-us-economic-disparity.

30 Saad Hasan, "Why China's Big Chip Breakthrough Has Rattled the US," TRT World, August 23, 2022, https://www.trtworld.com/magazine/why-china-s-big-chip-breakthrough-has-rattled-the-us-60048.

31 Todd Young, "Senator Young Floor Speech on His China Competitiveness Legislation Ahead of Final Vote," YouTube video, posted by Todd Young, July 27, 2022, https://youtu.be/1LLI6IOAbsg?t=371.

32 Angus Loten, "Chip-Making Push Expected to Boost U.S. Innovation,*Wall Street Journal*, September 20, 2022, https://www.wsj.com/articles/chip-making-push-expected-to-boost-u-s-innovation-11663709669.

33 David Rotman, "We're Not Prepared for the End of Moore's Law," MIT Technology Review, February 24, 2020, https://www.technologyreview.com/2020/02/24/905789/were-not-prepared-for-the-end-of-moores-law.

34 Hasssan N. Khan, David A. Hounshell, Erica R. H. Fuchs, "Science and Research Policy at the End of Moore's Law, https://www.nature.com/articles/s41928-017-0005-9.

35 Ibid.

36 "About Us," JobsOhio, https://www.jobsohio.com/about-us.

37 Glenn Kessler, "Biden's Bogus Boast of 1 Million 'Construction Jobs,'" *Washington Post*, August 18, 2022, https://www.washingtonpost.com/politics/2022/08/18/bidens-bogus-1-million-construction-jobs-boast.

38 Semiconductor Industry Association and Oxford Economics, "Chipping In: The U.S. Semiconductor Industry Workforce and How Federal Incentives will Increase Domestic Jobs," Semiconductor Industry Association, May 2021, 18–19, https://www.semiconductors.org/wp-content/uploads/2021/05/SIA-Impact_May2021-FINAL-May-19-2021_2.pdf.

39 Ibid, 19.

40 Will Hunt, "Reshoring Chipmaking Capacity Requires High-Skilled Foreign Talent: Estimating the Labor Demand Generated by CHIPS Act Incentives," Center for Security and Emerging Technology, February 2022, 3, https://cset.georgetown.edu/publication/reshoring-chipmaking-capacity-requires-high-skilled-foreign-talent.

41 Ibid, 4.

42 Ibid, 11.

43 David Autor, Kaushik Basu, Zia Qureshi, and Dani Rodrik, "An Inclusive Future? Technology, New Dynamics, and Policy Challenges," Brookings Institution, May 31, 2022, https://www.brookings.edu/research/an-inclusive-future-technology-new-dynamics-and-policy-challenges.

44 Ibtisam Abbasi, "How Far Can Semiconductor Manufacturing Be Automated?," Azo Materials, September 27, 2022, https://www.azom.com/article.aspx?ArticleID=22087.

45 For example, see Matt Mazewski and Christian Flores, "Economic Impacts of the CHIPS for America Act," Data for Progress, May 19, 2022, https://www.dataforprogress.org/memos/economic-impacts-of-the-chips-for-america-act.

46 U.S. Department of Commerce, "A Strategy for the Chips for America Fund," National Institute of Standards and Technology, September 6, 2022, 12, https://www.nist.gov/system/files/documents/2022/09/13/CHIPS-for-America-Strategy%20%28Sept%206%2C%202022%29.pdf.

47 Ibid.

48 Ibid, 15.

49 Dani Rodrik amd Stefanie Stantcheva, "A Policy Matrix for Inclusive Prosperity," Economics for Inclusive Prosperity, policy brief no. 30, April 2021, https://drodrik.scholar.harvard.edu/publications/policy-matrix-inclusive-prosperity.

50 Roslyn Layton, "The Security, Privacy And Supply Chain Problems Of The Chinese Military In Your iPhone," *Forbes*, April 15, 2022, https://www.forbes.com/sites/roslynlayton/2022/04/15/the-security-privacy-and-supply-chain-problems-of-the-chinese-military-in-your-iphone/?sh=5200a8475fad; John Villasenor, "Compromised By Design? Securing the Defense Electronics Supply Chain," Brookings Institution, November 2013, https://www.brookings.edu/wp-content/uploads/2016/06/villasenor_hw_security_nov7.pdf; and Defense Science Board, "Task Force Report: Resilient Military Systems and the Advanced Cyber Threat," U.S. Department of Defense, January 2013, https://dsb.cto.mil/reports/2010s/ResilientMilitarySystemsCyberThreat.pdf.

51 Catalin Cimpanu, "DHS Warns Against Using Chinese Hardware and Digital Services," *ZDNET*, December 22, 2020, https://www.zdnet.com/article/dhs-warns-against-using-chinese-hardware-and-digital-services.

52 Malek Ben Salem, "Security Challenges and Requirements for Industrial Control Systems in the Semiconductor Manufacturing Sector," Accenture, April 23, 2012, https://csrc.nist.gov/CSRC/media/Presentations/Security-Challenges-and-Requirements-for-Control-S/images-media/presentation-3_salem.pdf.

53 James Sanders, "Spectre and Meltdown Explained: A Comprehensive Guide for Professionals," *TechRepublic*, May 15, 2019, https://www.techrepublic.com/article/spectre-and-meltdown-explained-a-comprehensive-guide-for-professionals.

54 Jordan Robertson and Michael Riley, "The Long Hack: How China Exploited a U.S. Tech Supplier," *Bloomberg*, February 12, 2021, https://www.bloomberg.com/features/2021-supermicro.

55 Nicholas Weaver, "The U.S. Government Needs to Better Immunize Itself From Supply-Chain Attacks," Lawfare (blog), October 18, 2018, https://www.lawfareblog.com/us-government-needs-better-immunize-itself-supply-chain-attacks.

56 Semiconductor Industry Association and Boston Consulting Group, "Strengthening the Global Semiconductor Supply Chain in an Uncertain Era," Semiconductor Industry Association, April 2021 , 5, exhibit 1, https://www.semiconductors.org/strengthening-the-global-semiconductor-supply-chain-in-an-uncertain-era.

57 The mask is a "master template" of the chip. See "Photomask," Semiconductor Engineering,https://semiengineering.com/knowledge_centers/manufacturing/lithography/photomask.

58 Joshua Norem, "A Primer on Security of Key Stages in IC Manufacturing Lifecycle," EDN, April 19, 2022, https://www.edn.com/a-primer-on-security-in-the-key-stages-of-ic-manufacturing-lifecycle.

59 Ariel Levite, "ICT Supply Chain Integrity: Principles for Governmental and Corporate Policies," Carnegie Endowment for International Peace, October 4, 2019, https://carnegieendowment.org/2019/10/04/ict-supply-chain-integrity-principles-for-governmental-and-corporate-policies-pub-79974; and Paul Rosenzwig and Benjamin Wittes, "How Can One Know When To Trust Hardware and Software?," Lawfare (blog), May 2, 2022, https://www.lawfareblog.com/how-can-one-know-when-trust-hardware-and-software.

60 U.S. Department of Commerce, "A Strategy for the Chips for America Fund," 9–10.

61 Defense Microelectronics Activity, "DMEA Trusted IC Program," Defense Microelectronics Activity, https://www.dmea.osd.mil/TrustedIC.aspx.

62 Department of Defense Research & Engineering Enterprise, "Welcome to Trusted and Assured Microelectronics (T&AM)," Department of Defense Research & Engineering Enterprise, https://rt.cto.mil/ddre-rt/dd-rtl/tam.

63 Ensure Research Group, "Hardware Security," New York University, https://wp.nyu.edu/ensure_group/projects/hardware-security.

64 "Strategic Opportunities for U.S. Semiconductor Manufacturing: Facilitating U.S. Leadership and Competitiveness Through Advancements in Measurements and Standards," National Institute of Standards and Technology, August 2022, 18, https://nvlpubs.nist.gov/nistpubs/CHIPS/NIST.CHIPS.1000.pdf.

65 Erica R.H. Fuchs, "Building the Analytic Capacity to Support Critical Technology Strategy," Hamilton Project, Brookings Institution, September 28, 2022, https://www.hamiltonproject.org/papers/building_the_analytic_capacity_to_support_critical_technology_strategy.

66 White House, "Fact Sheet: Quad Leaders' Summit," September 24, 2021, https://www.whitehouse.gov/briefing-room/statements-releases/2021/09/24/fact-sheet-quad-leaders-summit.

67 Senate Commerce Committee, "Fact Sheet: Quad Leaders' Summit," 2022, https://www.commerce.senate.gov/services/files/1201E1CA-73CB-44BB-ADEB-E69634DA9BB9.

68 Megan Lamberth, Martijn Rasser, Ryan Johnson, and Henry Wu, "The Tangled Web We Wove: Rebalancing America's Supply Chains," Center for a New American Security, March 10, 2022, https://www.cnas.org/publications/reports/the-tangled-web-we-wove.

69 Chris Miller, "Rewire: Semiconductors and U.S. Industrial Policy," Center for a New American Security, September 19, 2022, https://www.cnas.org/publications/reports/rewire-semiconductors-and-u-s-industrial-policy.

70 Erica R.H. Fuchs, "Building the Analytic Capacity to Support Critical Technology Strategy."

71 U.S. Department of Commerce, "A Strategy for the Chips for America Fund."

72 Guy Chazan, "Germany Must Cut Gas Use by 20% to Avoid Winter Rationing, Regulator Says," *Financial Times*, August 14, 2022, https://www.ft.com/content/ca215782-a3ba-4a85-997d-19776 9275a50.

73 Semiconductor Industry Association and Boston Consulting Group, "Strengthening the Global Semiconductor Supply Chain in an Uncertain Era," *Semiconductor Industry Association*, April 2021, 5, exhibit 1; 11, exhibit 3, https://www.semiconductors.org/strengthening-the-global-semiconductor-supply-chain-in-an-uncertain-era.

74 Cyberspace Solarium Commission, "Cybersecurity Lessons from the Pandemic," Cyberspace Solarium Commission, May 2020, https://www.solarium.gov/public-communications/pandemic-white-paper.

75 John Reed, "India's High-Stakes Bid to Join the Global Semiconductor Race," *Financial Times,* September 1, 2022, https://www.ft.com/content/cbd50844-853e-4435-8028-f581d536a89a.

76 Christian Davies, Song Jung-a, Kana Inagaki, and Richard Waters, "US Struggles to Mobilise Its East Asian 'Chip 4' Alliance," *Financial Times*, September 12, 2022, https://www.ft.com/content/98f22615-ee7e-4431-ab98-fb6e3f9de032.

77 William Alan Reinsch, Emily Benson, Aidan Arasasingham, "Securing Semiconductor Supply Chains: An Affirmative Agenda for International Cooperation," Center for Strategic and International Studies, August 2, 2022, https://www.csis.org/analysis/securing-semiconductor-supply-chains-affirmative-agenda-international-cooperation.

78 For example, see Dani Rodrik amd Stefanie D, Stantcheva, S. "A Policy Matrix for Inclusive Prosperity"; and "Reimagining Industrial Policy for the Service and Tech Sectors," Hamilton Project at Brookings Institution, September 28, 2022, https://www.hamiltonproject.org/events/reimagining_industrial_policy_for_the_service_and_tech_sectors.

79 Anton Shilov, "TSMC: 2nm Chips Arriving in 2026," Tom's Hardware, April 15, 2022, https://www.tomshardware.com/news/tsmc-2nm-chips-to-be-available-in-2026.

80 Will Hunt, "Sustaining U.S. Competitiveness in Semiconductor Manufacturing Priorities for CHIPS Act Incentives."

81 Bernie Sanders, "NEWS: Sanders Opposes All Blank Checks to Chip Companies," press release, July 15, 2022, https://www.sanders.senate.gov/press-releases/news-sanders-opposes-all-blank-checks-to-chip-companies.

82 "Reimagining Industrial Policy for the Service and Tech Sectors," Hamilton Project at Brookings Institution.

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