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Securing Semiconductor Supply Chains

An Affirmative Agenda for International Cooperation

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Introduction

Technological innovation has been a driving force for U.S. global leadership and economic prosperity for over a century. This legacy of innovation largely stands on the foundation of a key component: semiconductor chips, found today in almost all electronic products. Semiconductors are an integral component of various consumer products across industries, including cars, smartphones, and household appliances. But semiconductors can also be used in dual-use goods—products that have both military and civilian applications—such as air guidance systems for both civilian and military aircraft. The tension between economic gain and security risk inherent within dual-use semiconductor goods is heightened in fields with national security implications, such as supercomputing and artificial intelligence (AI). How the government and private sector manage the global value chains (GVCs) of chips will directly affect U.S. global competitiveness and national security going forward.

The past two years have underscored the importance of semiconductors to the U.S. economy and its national security interests. Pandemic-induced spikes in consumer demand boosted semiconductor demand by 17 percent between 2019 and 2021. Global sales reached $555.9 billion in 2021, 26.2 percent more than the year before. Although China remains the largest market in the world for semiconductors, sales in the Americas represented the largest region for industry growth in 2021. However, this spike in demand, along with stagnating investment, inadequate input supplies, and logistics breakdowns, has led to an unprecedented shortage of semiconductors that has reverberated throughout the roughly 200 downstream industries that depend on chips. In the automotive industry alone, it was projected that global semiconductor shortages were responsible for $210 billion in lost revenue as of September 2021.

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Short-term supply chain disruptions for the semiconductor industry are compounded by long-term geopolitical challenges and the need to rethink what constitutes both secure and resilient supply chains. While China is a top customer for the semiconductor industry, the perception of China has shifted in recent years from potential partner to existential threat. This shift has led companies and countries alike to rethink their dependency on China as both partner and customer. In particular, the Biden administration has sought policies that attempt to accelerate progress and prolong the United States' innovative edge, while simultaneously dampening China's influence throughout the semiconductor marketplace. Countries around the world have begun thinking about ways to reduce dependencies on China, enhance supply chain resiliency, and keep costs down.

In the United States, this confluence has manifested in calls for nearshoring and "friend-shoring." As Treasury Secretary Janet Yellen said in April 2022 **remarks**, "friend-shoring means . . . that we have a group of countries that have strong adherence to a set of norms and values about how to operate in the global economy and about how to run the global economic system, and we need to deepen our ties with those partners and to work together to make sure that we can supply our needs of critical materials." The key **difference** between onshoring and friend-shoring is that friend-shoring is not restricted to domestic production, but rather seeks to move production to allied partners.

While moving supply chains away from East Asia could increase security in the long run, an ill-conceived implementation of this friend-shoring strategy could result in price hikes and a stronger China over time. In its 2022 **capstone report** on supply chains, the Biden administration explicitly stated that "the United States cannot make, mine, or manufacture everything ourselves. We must cooperate with our allies and partners to foster and promote collective supply chain resilience." Thus emerges the need for the United States to choose its partners wisely when it comes to semiconductor supply chains.

As the United States considers how to build more secure and resilient supply chains, it should seek closer collaboration with countries demonstrating the following characteristics: (1) the bloc should maintain robust support for technology development, whether through a conducive regulatory environment or significant government investment in research; and (2) as a matter of national security, the United States should enhance cooperation only with those parties whose export controls are consistent with its own, including compliance with the Foreign Direct Product Rule (FDPR).

The United States is already leveraging relationships with foreign partners to enhance semiconductor supply chain resiliency; increase collaboration on distortive trade practices, investment screening, and export controls; and enhance transatlantic cooperation regarding secure internet and communication technology (ICT) supply chains. In its first year, the Biden administration pursued closer security relationships with both selected Asian countries and the European Union. In May 2022, the United States and the European Union held the second ministerial of the **U.S.-EU Trade and Technology Council** (TTC). The TTC seeks to promote closer transatlantic collaboration through 10 specific working groups, including rebalancing transatlantic semiconductor supply chains. The joint statement from the second ministerial underscores the need to build more geographically and commercially diversified supply chains and directly highlights an overdependence on China for the production and processing of certain inputs. In the supply chain annex, the parties agreed to develop an early warning and monitoring mechanism on semiconductor value chains, monitor and prepare for supply chain disruptions, and enhance transparency and commit to exchange information to avoid a subsidy race. These types of generalized commitments are relatively easy to put forth, but much more difficult to achieve in practice.

Dealing with Russia's invasion of Ukraine has also become a major focus of TTC activity, particularly regarding cooperation on sanctions and export controls. The united export control response is intended to cripple Russia's war machine by cutting the country's military off from advanced technologies like semiconductors, which are used in military goods like aircraft and tanks. Continued close coordination on sanctions is expected, but whether that will translate into the same level of cooperation outside the Ukraine context remains to be seen. Furthermore, the U.S. focus on export controls in the sector, coupled with the Russian invasion of Ukraine and mounting Chinese pressure on Taiwan, has injected a new level of national security discourse into the trade policy debate.

In addition to closer collaboration with the European Union, the Biden administration has accelerated its engagement with Asian partners. In September 2021, the United States, Japan, India, and Australia launched a "joint initiative to map capacity, identify vulnerabilities, and bolster supply-chain security for semiconductors and their vital components" as part of their Quad alliance. Quad leaders also convened in May 2022, though the meeting largely centered on security issues. It is unclear how these EU and Quad semiconductor supply chain efforts will progress, but each comes with different economic and national security implications.

Another evolving initiative is the Indo-Pacific Economic Framework for Prosperity (IPEF). All of the Quad countries have indicated their intent to participate in the IPEF, though they have not yet announced which specific pillar negotiations they will join. While details of the framework remain elusive, the IPEF launch in May 2022 confirmed that the framework will consist of four primary policy pillars: (1) trade; (2) supply chain resiliency; (3) infrastructure, clean energy, and decarbonization; and (4) tax and anti-corruption. The United States Department of Commerce will lead supply chain resiliency, infrastructure and decarbonization, and tax and anti-corruption. The Office of the United States Trade Representative (USTR) will head the fair and resilient trade component. It is likely that the Commerce Department will leverage the supply chain resiliency pillar to collaborate more closely with Indo-Pacific partners on semiconductor supply chains, including early warning systems for shortages and information sharing on how to avert future supply chain crunches. That Australia and Japan are likely participants in the USTR's trade pillar provides the United States with a forum for governments to redouble efforts toward strengthening semiconductor GVCs and cooperation, though Indian participation in the trade pillar remains highly unlikely. Export controls will not be one of the topics covered in the IPEF.

Given the evolving security relationship between the United States, the Quad, and the European Union, this paper focuses on both Quad and EU countries and the possibilities for friend-shoring in both. It assesses how the EU and U.S. governments can collaborate to avoid duplicative policies that fail to enhance the overall resiliency of transatlantic semiconductor supply chains. In addition to analyzing opportunities for closer cooperation across governments, this paper also evaluates policies the U.S. government should pursue to support the private sector and ensure the long-term competitiveness of the U.S. semiconductor industry. The paper also looks at another emerging security partnership among the Quad countries to assess their viability in terms of semiconductor friend-shoring. This project looks at the current landscape of semiconductor research and development (R&D), fabrication, and packaging capacity in these case study countries; evaluates export control regimes in each country; and assesses which countries are best positioned to partner with the United States to build more resilient semiconductor supply chains based on economic and national security considerations.

This paper finds that, given the inherent and increasing complexity of global semiconductor supply chains, self-sufficiency in semiconductor production is probably unattainable and, in any event, would be counterproductive in the short term and would contravene long-term geostrategic interests that depend on continued innovation and competitiveness. China's persistent pursuit of intellectual property theft and subsidization of domestic production underscores how important it is for the United States to engage more closely with like-minded allies to bolster the security of analog and next-generation chips. What emerges is the need for an affirmative agenda for semiconductor supply chains among allies. Key recommendations emerged from interviews conducted for this research, including the need to

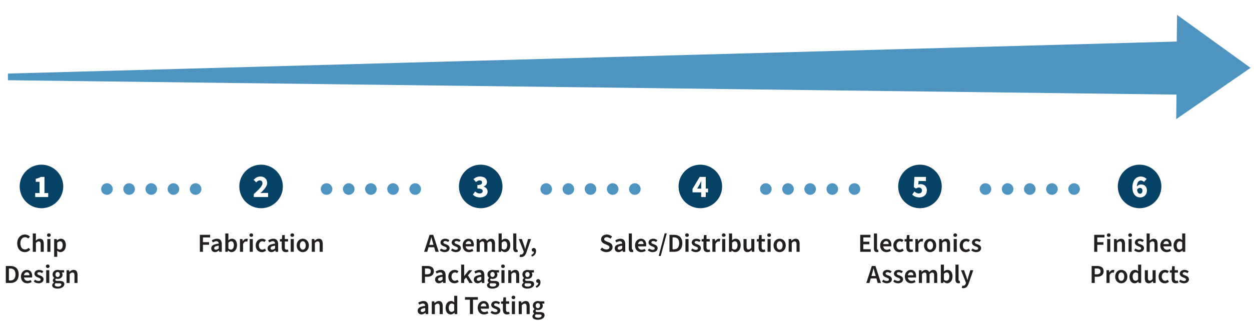
- identify policy goals that would help bolster semiconductor supply chain resiliency;
- promulgate consistent, predictable policies, particularly related to trade;
- avoid blanket export controls that risk dampening investment in allied semiconductor industries; and
- consider the creation of a new mini-export control regime that could function similarly to the Wassenaar Arrangement.

Using these key themes, this paper assesses specific case study countries to evaluate how governments can better support the semiconductor industry.

The Global Semiconductor Value Chain

The global semiconductor value chain is dominated by the United States, Taiwan, South Korea, Japan, Europe, and China. The semiconductor GVC consists of three main stages: R&D (chip design), fabrication (chip production), and advanced testing and packaging (back-end manufacturing). R&D and chip design require substantial funding and human capital input; consequently, the industry has one of the highest R&D margins across all industries. Semiconductor companies spend more than 18 percent of their revenue on R&D. Fabrication (fab) involves the production of chips, a deeply technical and precise six-step process. Front-end manufacturing requires significant capital expenditures. For example, a standard semiconductor fab requires roughly $5 billion of investment, while an advanced fab can cost over $20 billion.

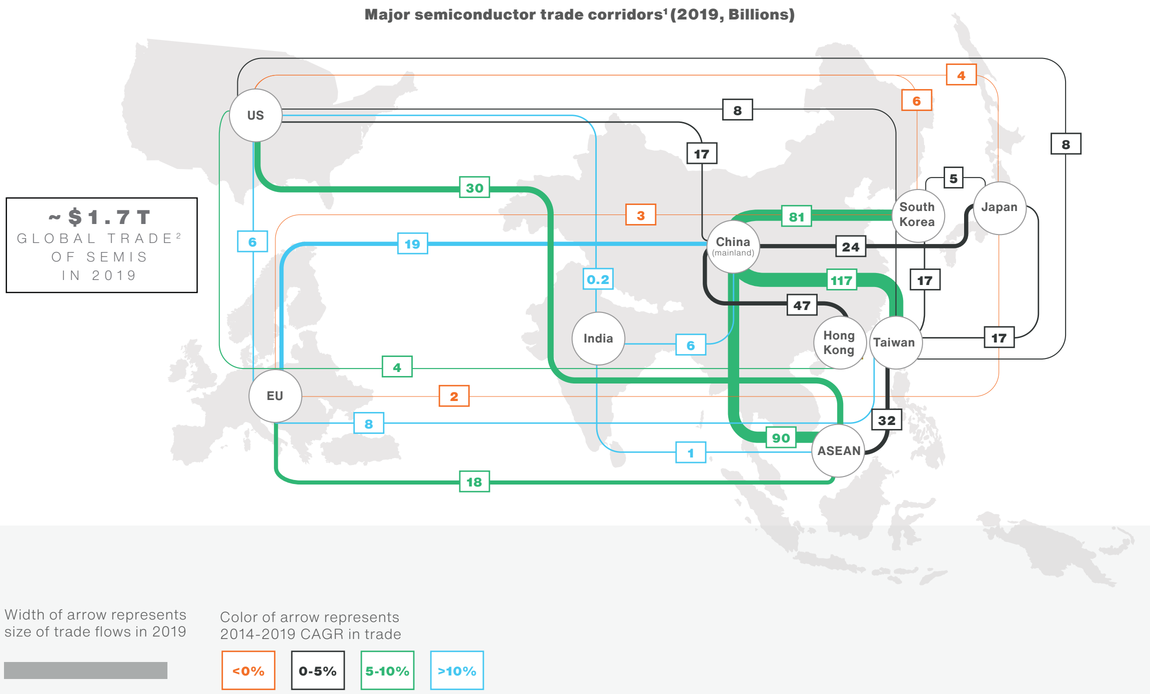
Semiconductor Value Chain



Source: CSIS Scholl Chair.

The fabless foundry model allows firms to specialize in one primary aspect of the semiconductor GVC and to outsource manufacturing. For example, chips might be designed in Silicon Valley, manufactured in East Asia with Dutch machine tools, and then packaged in Malaysia. U.S.-based Qualcomm specializes in the design of semiconductors and does not have production facilities, while companies like Global Foundries specialize in manufacturing and do not do their own design. Meanwhile, companies such as Amkor specialize in assembly, testing, and packaging (ATP), also known as back-end manufacturing.

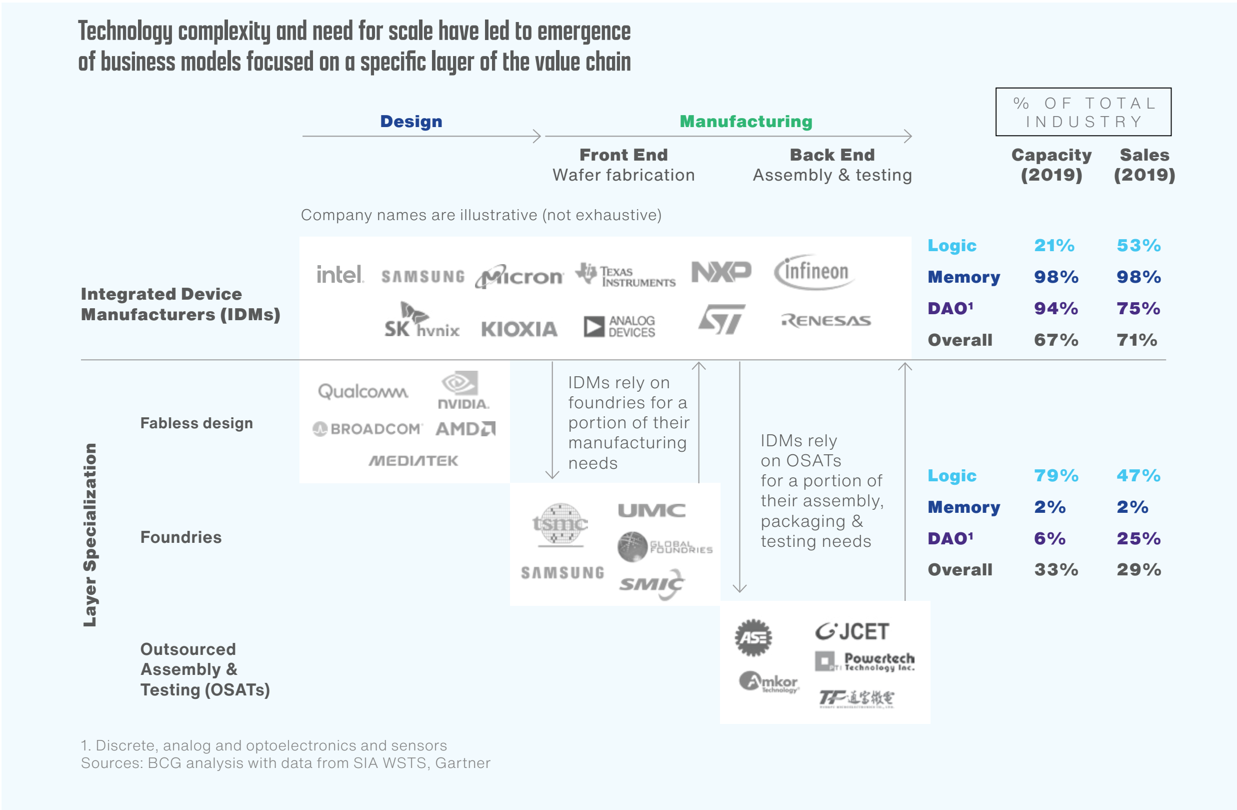
A large web of global trade flows supports the geographic specialization in the semiconductor value chain



1. HS codes 8541, 8542, minus HS 854140, excludes semiconductor equipment
2. Includes both exports and imports. Note: Significant disparities in reported data by each country. Importer data used where possible;
Source: IHS Global Trade Atlas, UN Comtrade; BCG analysis

Source: Antonio Varas, Raj Varadarajan, Jimmy Goodrich, and Falan Yinug, *Strengthening the Global Semiconductor Supply Chain in an Uncertain Era* (Boston Consulting Group and Semiconductor Industry Association, April 2021), 37, https://www.semiconductors.org/wp-content/uploads/2021/05/BCG-x-SIA-Strengthening-the-Global-Semiconductor-Value-Chain-April-2021_1.pdf.

Back-end manufacturing is typically handled by outsourced semiconductor assembly and test (OSAT) companies. Taiwanese companies maintain 53 percent of the back-end market share, though the United States International Trade Commission finds there is a "notable concentration" of ATP service providers in Malaysia, Indonesia, Thailand, and Vietnam. In 2019, Taiwan maintained 53 percent of the OSAT market, and a single Taiwanese firm, ASE Group, maintained 26 percent of the global back-end market. The largest OSAT firm in the United States is Amkor Technologies, which accounted for 13 percent of the market in 2019. While ATP services account for only 10 percent of a chip's value, they are the important last step in the production process. On the other hand, the integrated device model (IDM) represents the vertical integration of semiconductor GVCs. Few firms follow the IDM. However, IDM sales reached $257.4 billion, while fabless chip sales reached $127.9 billion, underscoring the profitability derived from the efficiency of vertical integration models. Examples of these vertically integrated firms include Intel, Samsung, and Texas Instruments.



Source: Varas, Varadarajan, Goodrich, and Yinug, *Strengthening the Global Semiconductor Supply Chain in an Uncertain Era,* 24.

Semiconductor Policy in the United States

While semiconductor GVCs are distributed around the world, diversification of GVCs helps keep costs down and reduces the likelihood of a major disruption. One month into office (in February 2021), President Biden signed an Executive Order on America's Supply Chains. The order mandated that relevant agencies undertake a comprehensive review U.S. supply chain security in the following key areas: semiconductor manufacturing and advanced packaging, batteries, critical minerals and materials, and pharmaceuticals. With respect to semiconductors, the 100-Day Review found that while the United States remains a leader in design, lack of production capacity and continued reliance on foreign manufacturers continue to restrain industry growth.

The Commerce Department, which oversaw the review of semiconductor supply chains, found in its one-year review that chip shortages were particularly acute in certain types of semiconductors. These include legacy logic chips, such as those used in medical devices and automobiles, analog chips used in power management and image sensors, and optoelectronic chips used in sensors and switches. These categories of chips are relatively large in nanometer size, meaning increasing supply is relatively easier to achieve than with other, more advanced chips.

A combination of factors in the United States, such as high labor costs and insufficient government-supported R&D, has led to a decrease in the U.S. share of semiconductor manufacturing capabilities, from 37 percent in 1990 to 12 percent in 2019. In light of ongoing disruptions to semiconductor supply chains and a decreasing U.S. market share, the Biden administration has deemed this a national security priority. As directed by the February 2021 executive order, the Commerce Department released its 100-day critical supply chain report the following June, providing a comprehensive overview of risks, vulnerabilities, and opportunities to strengthen and secure U.S. semiconductor supply chains. Also in June 2021, the United States Senate passed the United States Innovation and Competition Act (USICA), followed by the House version—the America Creating Opportunities for Manufacturing, Pre-Eminence in Technology, and Economic Strength Act of 2022 (the America COMPETES Act). These bills, currently in conference, both contain the Creating Helpful Incentives to Produce Semiconductors for America Act (the CHIPS for America Act), which would provide substantial investments to boost domestic semiconductor production—to the tune of over $52 billion. In the backdrop of geostrategic competition with China, the Biden administration's approach to semiconductor investment represents a desire to scale up U.S. industry and maintain a competitive edge for U.S. semiconductor manufacturing.

The CHIPS for America Act would allocate $39 billion to the Commerce Department's semiconductor incentive program, providing up to $3 billion per firm for the construction of new fabs. It would allocate roughly $11 billion for R&D. Additionally, the act would create a new Multilateral Semiconductors Security Fund to promote the development of a secure semiconductor supply chain. The act would also establish new supply chain programs within the Commerce Department. CSIS outlines additional contours of the CHIPS for America Act in this piece.

According to the act, U.S. government spending on semiconductors would complement existing industry efforts to bolster the resiliency and security of semiconductor supply chains. As of 2020, the United States accounted for the largest portion of the semiconductor market share, at 47 percent, equaling $207.9 billion in sales. Major private players are making sizable investments in the domestic semiconductor industry, including to increase domestic production capacity. In 2022, Intel announced it would invest $20 billion in building two Ohio factories. Taiwan Semiconductor Manufacturing Company (TSMC) concluded a deal to spend $12 billion in Arizona to develop a new plant. Texas Instruments plans to invest $3.5 billion annually for chip manufacturing in the United States through 2025.

INVESTMENT SCREENING, EXPORT CONTROLS, AND TRADE INITIATIVES

Trade policy is an important part of facilitating the development of a resilient semiconductor industry. Trade policies can be tools that enhance innovation and growth, while at the same time restraining the ability of adversaries to develop cutting-edge technologies. The task for policymakers is to ensure that policies to promote industry growth do not conflict with ones to protect national security. Trade policy can play an important role in helping domestic industry "run faster" against competition, but excessive technology controls in the name of national security can have the unintended effect of denying U.S. high-tech companies the revenue they need to innovate and grow.

The United States has a robust policy tool kit for building more resilient semiconductor supply chains while advancing national security measures. In 2018, Congress passed legislation that enhanced government capabilities to review both foreign investments and domestic outflows. The Export Control Reform Act of 2018 (ECRA) provides the president with the authority to establish new export controls on "emerging" and "foundational" technology—though ECRA did not explicitly define either of those terms, leading to significant uncertainty throughout the private sector. The designation of semiconductors as foundational could result in wide-ranging license requirements for standard chips used in everyday items. However, the Bureau of Industry and Security recently announced in a proposed rule that it was no longer going to distinguish between emerging and foundational designations. Designating semiconductors as foundational could potentially dampen U.S. private-sector profits, thereby restraining the industry's ability to invest in next-generation R&D.

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Another trade tool the United States has implemented administratively is the FDPR. The FDPR is an extraterritorial application of U.S. law that permits the government to curb foreign-produced exports containing U.S. equipment or technology, including design, to those on the Entity List. Following the Russian invasion of Ukraine in February 2022, the Biden administration announced it would apply the rule to Russia. The FDPR imposes new license requirements on exports to Russia and applies a policy of denial to license applications for exports or reexports to Russia or for transfers within the country. Overall, the application of the rule significantly restricts Russia's ability to acquire critical goods like microelectronics, telecommunications items, and aircraft components. Key to compliance is whether foreign trading partners, such as China, will adhere to secondary sanctions—such as the FDPR—that will affect the production, thereby restricting foreign availability of covered products. The European Union and Japan have adopted restrictive measures similar to those of the United States. South Korea has agreed to comply with Western sanctions but has indicated it will not implement its own. In February 2022, Taiwan announced it would also join Western sanctions, and in April 2022, Taiwan initiated its own export curbs on products to Russia, adding 57 products to a new export control list. Nevertheless, it is uncertain whether other trading partners—namely, China and India—will comply with Western export controls, thereby restricting the outflow of semiconductors made with U.S. inputs or design. Furthermore, it remains to be seen whether Western agreement on Russia sanctions will extend beyond the Ukraine conflict—for example, in the event of a Chinese invasion of Taiwan.

Another policy tool that could affect collaboration on semiconductor supply chains between the United States and foreign partners is a new outbound investment-screening tool that has been proposed by Senators Casey (D-PA) and Cornyn (R-TX). The Senators' bill would establish an interagency process to review outbound investment in areas of "national critical capabilities" to entities "of concern." A similar proposal exists in the House's America COMPETES Act as well. Proponents of outbound investment screening argue that the outflow of U.S. investment to China bolsters Chinese critical industries, threatening U.S. national security interests. Although critics of the proposal argue it would duplicate the Department of the Treasury's remit to screen investments, proponents believe this could be a useful mechanism for ensuring that U.S. funds are not used to enhance technological capabilities of foreign adversaries, including bolstering advanced semiconductor manufacturing.

Trade and investment policy affects where firms decide to locate and plays a key role in determining which countries can acquire sensitive technologies, and in turn, which types of sensitive technologies are permitted to leave those countries. For trade policy to succeed in achieving desired geopolitical outcomes, it needs to be based on determined end goals and on a calculation of how best to achieve those goals. Part of this consideration requires governments and firms to take into account foreign availability of equivalent products. If most, but not all, countries converge to reduce the export of sensitive chips to adversaries, it remains likely that the adversarial countries will be able to acquire chips from nonparticipating third countries. It is therefore crucial for the United States to work in concert with like-minded countries as it decides whether to encourage or require restrictions on technologies such as semiconductors. Building secure semiconductor GVCs thus requires multilateral cooperation among governments of foreign semiconductor producers, whether specializing in R&D, production, or back-end packaging. It is also incumbent on companies to be familiar with policy developments in this area and make location and investment decisions consistent with them.

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MULTILATERAL INITIATIVES

In addition to U.S. policies that affect the trade and security of semiconductors, there are multilateral trade arrangements that create governance structures for chips and other dual-use goods. The Wassenaar Arrangement on Export Controls for Conventional Arms and Dual-Use Goods and Technologies is a multilateral export control regime formally established in the Netherlands in 1996. Currently, 42 states participate in this regime,[1] which aims to promote transparency and responsibility in transfers of arms and dual-use goods and technologies, including semiconductors. All Quad countries are members of the Wassenaar Arrangement. There are significant limitations to the Wassenaar Arrangement—namely, the slow pace of its decisionmaking and its role to advise and notify, rather than constrain, trade. Furthermore, Russia's membership in the arrangement is a factor that makes it difficult for the framework to function effectively.

With executive branch efforts to build more resilient and secure semiconductor supply chains, along with proposed legislation that would provide historic amounts of semiconductor funding, the U.S. government has made the production of chips a top priority that intersects with both economic and national security strategic objectives. As the United States builds the foundation for the next generation of its technological sovereignty, it is confronted with the inherently global nature of semiconductor GVCs and must reconcile the need to promote U.S. industry while protecting national security interests. R&D often occurs in the United States and in Taiwan, while the Netherlands is a key exporter of the machine tools to produce chips. Packaging, meanwhile, occurs primarily in East Asian countries. Recognizing that total onshoring is neither feasible nor desirable, it is important to evaluate which countries could help the United States build more secure semiconductor supply chains.

Semiconductor Policy in EU Member States

Coinciding with the United States' review of its critical semiconductor supply chains, the European Union has also had a reckoning with its own dependency on foreign producers in critical areas and has reassessed how to enhance its technological sovereignty. In 1990, Europe produced nearly 35 percent of semiconductors globally, but that number has dropped to roughly 9 percent as of 2020. In general, the European Union lags in the final step of the semiconductor value chain—back-end manufacturing—which involves the assembly, testing, and packaging of chips. Globally, only 5 percent of that capability is located in Europe. Even if an increased number of semiconductor wafers are made in Europe, they would still be sent elsewhere, such as China, for packaging.

1. Argentina, Australia, Austria, Belgium, Bulgaria, Canada, Croatia, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, India, Ireland, Italy, Japan, Latvia, Lithuania, Luxembourg, Malta, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russia, Slovakia, Slovenia, South Africa, South Korea, Spain, Sweden, Switzerland, Turkey, Ukraine, the United Kingdom, and the United States.

In September 2021, the European Union announced a legislative package parallel to that of the United States—the European Chips Act—which it formally introduced in February 2022. The European Chips Act intends to reinforce European commitment to significant investments in semiconductors through R&D, fabrication, production, and support to small and medium-sized enterprises (SMEs). The act consists of three main policy pillars: (1) the "Chips for Europe Initiative," which supports capacity building through increased investment; (2) "security of supply" through the creation of first-of-a-kind advanced facilities; and (3) preparedness and monitoring to avert supply chain crunches.

The act will also work to build stronger supply chains with the United States and with Japan. Given the semiconductor shortage of the past two years, the European Commission intends to strengthen European R&D leadership, improve upon its capacity to innovate in design and manufacturing, and significantly increase its production capacity by 2030. The act also bolsters the Alliance on Processors and Semiconductor Technologies, which seeks to identify gaps in microchip production by reinforcing the European electronics design ecosystem and increasing manufacturing capacity, including testing and advanced packaging. These efforts complement the European Union's Digital Decade strategy, which establishes an agenda for European digital transformation by 2030.

European investment in semiconductor production has raised questions about subsidies—known as "state aid" in the European Union—particularly related to Important Projects of Common European Interest (IPCEIs). IPCEIs are cross-border initiatives led by member states that can contribute to EU strategies. Since this constitutes state aid, these initiatives must seek approval from the commission. In November 2021, the European Commission adopted revised state aid rules for these projects, which establish criteria for the commission to assess "member state support to cross-border IPCEIs that overcome market failures and enable breakthrough innovation in key sectors and technologies and infrastructure investments, with positive spillover effects for the EU economy at large."

These revised guidelines state that IPCEIs must meet the following criteria: (1) involve at least four member states, (2) be designed in a transparent and inclusive manner, (3) facilitate SME participation, and (4) align their objectives with current EU priorities, such as the green transition. The guidelines also include safeguards to ensure that the aid is proportional and prevents any undue market distortions. These subsidies would generally fall under the ambit of the Agreement on Subsidies and Countervailing Measures under World Trade Organization rules. If the effects of such subsidies are determined to be injurious, they can be countervailed by other countries, which could have the net effect of restricting semiconductor trade and driving up costs. There are six requirements for IPCEIs and none of the requirements prohibit the inclusion of non-European companies in such projects. Thus, nominally, a U.S. company could benefit from IPCEI funds. Only four IPCEIs have ever been notified and assessed by the commission. Two were infrastructure projects that did not include non-European companies. The other two IPCEIs involved strategic value chains and did include non-European companies. Murata (in Japan) and Cortec (in the United States) took part in the microelectronic IPCEI, and Endurance Technologies (in India) participated in the battery IPCEI. However, the vast majority of companies that participated in these two IPCEIs were still European.

Overall, the existence of IPCEIs presents companies with added benefits when partnering with the European Union on semiconductor supply chains. First, IPCEIs offer additional funding revenues. Second, they leverage the European Union's integrated single market, which makes it relatively easier to build a semiconductor ecosystem, with parts of the supply chain split among countries to leverage the capabilities of specific member states. Although IPCEIs are projects led and funded by the government, multinational private firms are not restricted from obtaining that funding.

The next section of this paper evaluates which EU member states are best positioned for increased semiconductor collaboration with the United States. While some degree of redundancy in semiconductor supply chains can help increase overall resiliency, the transatlantic alliance should attempt to avoid duplicative spending on chips where possible. The member states assessed below possess existing semiconductor infrastructure and are poised to expand domestic capabilities.

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BELGIUM

Belgium's central location between Europe's major economic powers makes it a natural crossroads for the semiconductor industry and European diplomacy. Most economic activity is concentrated in Flanders, the Dutch-speaking northern region of Belgium, where many Belgian high-technology and services firms are based.

R&D Capacity: Belgium is a top player in the global semiconductor R&D supply chain. Belgium ranks fifth on the European Innovation Scoreboard. Flanders is home to five research universities and four strategic research centers. Specific to semiconductor R&D, Belgium had the fifth-highest accumulated number of paper contributions to semiconductor research between 1995 and 2020.

The crown jewel of Belgium's semiconductor R&D industry is the Interuniversity Microelectronics Center (Imec) in Leuven, one of the world's top semiconductor R&D institutes. Imec boasts 12,000 square meters of cleanroom and lab capacity and a workforce of over 5,000 researchers from 95 countries across its facilities. Imec's $3 billion experimental pilot line is one of its top attractions, allowing researchers to develop limited quantities of leading-edge chips two or three generations ahead of current leading-edge manufacturing with a new 2D graphene-based process. Imec often refers to itself as "the Switzerland of semiconductors" to highlight its corporate and geopolitical neutrality. Although the Belgian government funds 16 percent of its $773 million budget, no single firm or state has a controlling stake. As a result, Imec holds a unique place as a convener in the global semiconductor industry and a nexus of basic and applied research.

The Biden administration has taken note of Imec's industry centrality, noting its geopolitical importance in its supply chain 100-day review. Under the European Chips Act, Imec would receive over €1 billion ($1.1 billion) in public funding to create new test line facilities to speed the transition from the R&D of leading-edge chip technology to its commercialization. The United States Department of Commerce and the National Institute of Standards and Technology have also identified Imec as a potential partner for overlapping with or complementing U.S. efforts to build a stronger domestic semiconductor industry.

Fab Capacity: Belgium is home to only one fab, U.S.-based Onsemi's Oudenaarde manufacturing facility. The 40,000 square foot fab produces six-inch wafers at the 350–2000nm level for mostly automotive and industrial application, but no leading-edge chips. In February 2022, Belgian firm BelGaN Group BV acquired the Oudenaarde manufacturing facility.

Benefits and Risks: Belgium's central location and role in the European Union, along with its robust R&D ecosystem and transportation linkages to major European markets, make the country an attractive location for semiconductor investment. However, the United States International Trade Administration warns that Belgium's shortage of STEM labor limits the country's R&D and high-tech manufacturing potential. Compared to other case study countries in this report, Belgium has the lowest percentage of tertiary graduates from STEM programs, roughly equal to only 17 percent of total graduates, according to data from the European Commission. In Belgium, 72 percent of young adults enroll in a bachelor's program or equivalent by the age of 25, the highest rate among member countries of the Organization for Economic Cooperation and Development (OECD). Nevertheless, only 0.8 percent of working-age Belgians have a doctoral degree, which ranks below the OECD average. While Belgium's streamlined policies for high-skill immigration partially offset this relative shortcoming, the country's more limited number of STEM graduates is a factor that could affect its ability to compete against other countries with a larger talent pool.

THE NETHERLANDS

The Netherlands is a semiconductor powerhouse, one of the few countries in the world with a fully integrated vertical semiconductor supply chain. This includes applied research, chip design, chip architecture, chip production, and system integration and applications. The Dutch have also effectively dominated the machine tool portion of the semiconductor supply chain in Europe. Businesses in the Netherlands generate the highest average sales in the semiconductor industry, accounting for €4.4 billion ($4.8 billion) annually. The four companies that predominantly make up the industry are ASM International, ASML, BE Semiconductor Industries (Besi), and NXP Semiconductors (NXP). The Netherlands is also home to several companies that provide equipment to the semiconductor manufacturing industry. For instance, ASML is the largest supplier of photolithography systems for the semiconductor industry worldwide and is also involved in the production of 5 nm chip technology.

R&D Capacity: ASML is the world's largest supplier of lithography equipment, which is integral in transferring circuit patterns onto wafers. ASML's sales reached $6.5 billion in 2020, and it is the sole supplier of extreme ultraviolet (EUV) lithography machines, which it unveiled in 2019. EUV machines use extreme ultraviolet wavelengths to print the most intricate layers of chips, creating advanced and highly complex semiconductors to achieve "big things on a tiny scale." ASML's control of EUV has led some competitors to claim that ASML maintains monopolistic control over the lithography industry. While ASML largely controls the lithography machine side of the supply chain, Intel, Samsung, and TSMC also produce high-grade chips. ASML's position as the sole provider of EUV machines makes them an ideal partner for companies like Intel and TSMC. In a 2012 deal, Intel acquired a 15 percent ownership stake in ASML.

Fab Capacity: The Netherlands is also home to ASM International (ASMi), which was founded in 1968. ASM pioneered technologies such as lithography, deposition, ion implant and single-wafer epitaxy. ASMi also holds a 25 percent stake in ASM Pacific Technology (ASMPT), which was founded in Hong Kong in 1975 and, at the time, was the most productive vertical furnace in the semiconductor industry. Vertical furnaces are key to productivity because they allow a stack of wafers to be loaded into a furnace for simultaneous processing. ASMi's subsidiary, ASMPT, focuses mostly on assembly and packaging. ASMi was involved throughout the chip-making process, from unprocessed silicon wafers to packaged chips. Recently, they have made breakthroughs in atomic layer deposition and plasma-enhanced atomic layer deposition, developing the concept from R&D through production. Their primary focus today is on front-end wafer processing.

Besi, another prominent Dutch semiconductor company, is engaged in the development, manufacturing, marketing, sales, and service of semiconductor assembly equipment. It operates seven facilities in Asia and Europe for production and development. Besi is involved in the development and supply of die attach equipment, packaging equipment, plating equipment, and service equipment. R&D is spread across Europe, North America, and Asia, while manufacturing occurs largely in Singapore, South Korea, and the Netherlands.

Benefits and Risks: The Netherlands is an attractive partner for closer U.S. collaboration for several reasons. In the 2021 International Institute for Management Development (IMD) World Competitiveness Ranking, the Netherlands ranked fourth overall, surpassed by Switzerland, Sweden, and Denmark. The Netherlands placed second for overall economic performance, fourth for business efficiency, and seventh for infrastructure. The country also scored well on international trade, international investment, and technology infrastructure. The most recent edition of the World Economic Forum's Global Competitiveness Index, in 2019, also ranked the Netherlands as the most competitive country in Europe.

The Netherlands also excels in education. Dutch expenditures on higher education are 30 percent higher than the OECD average and its expenditures on R&D are the sixth highest in the OECD. Furthermore, the Netherlands has a comparatively internationalized higher education system, meaning it succeeds in attracting foreign talent to complement its domestic workforce. Among doctoral students, 43 percent are international, the majority of which come from other European countries.

Other attractive features of the Netherlands are its geographic location and its top-tier infrastructure. Its location affords the country easy access to other European capitals and to an extensive international trade network that facilitates cross-channel flows to the United Kingdom and transatlantic flows to its North American partners. The Port of Rotterdam, Europe's largest port, is a key facilitator of the country's robust international trade profile.

The Netherlands has also recently acquiesced to U.S. demands for cooperation on export control issues. In 2018, the Dutch government provided ASML with an export license to send advanced lithography equipment to China, thereby enabling China to produce its own chips. The Trump administration, fearful about Chinese acquisition of these advanced machine tools, sought to outright ban the transfer of lithography equipment from the Netherlands to China. Pressure from the Trump administration ultimately prevailed, and the Netherlands reversed the license. While transatlantic cooperation ultimately prevailed in this case, Dutch cooperation on export controls was reluctant and only followed significant pressure from the U.S. government.

NXP, in particular, has had to placate both U.S. and Chinese regulatory authorities in recent years. In 2015, the United States Federal Trade Commission required that NXP divest its radio-frequency power amplifier before it approved NXP's acquisition of Freescale, a U.S. semiconductor company. NXP acquiesced and sold the unit to a Chinese state-owned investment management firm. After the merger with Freescale, NXP further divested and sold its standard products business to the same Chinese firm in 2016. Finally, in 2018, Qualcomm attempted to acquire NXP, and NXP sold its stake in a Chinese chip-design joint venture in an attempt to appease Chinese regulatory authorities, who ultimately failed to approve the Qualcomm-NXP merger. These actions suggest that NXP and the Dutch have worked to placate Chinese authorities and have sought to play the middle ground in order to maintain access to both the Chinese and U.S. markets. Overall, the ASML and NXP cases underscore that the Netherlands will continue to contend with not only political pressure from the U.S. government, but also the continued attractiveness of the Chinese market.

While the Netherlands and the European Union have demonstrated a willingness to comply with the extraterritorial application of U.S. export controls, the case with ASML demonstrates the importance of allied collaboration regarding long-term geopolitical goals, since restricting which countries can access advanced manufacturing tools can help or hinder their bid for technological superiority. Overall, given the Netherlands' abundance of water, highly trained workforce, and closer cooperation with the U.S. government on export controls, it continues to remain one of the best options for U.S. foreign collaboration on semiconductor GVCs.

FRANCE

France is the second-largest economy in the European Union and maintains a significant presence in the European semiconductor industry, with centers for R&D, manufacturing, and packaging. In 2019, France exported €1.05 billion ($1.15 billion) in semiconductor devices, primarily to Singapore, Germany, China, and the Netherlands. The French semiconductor industry will receive not only support from the EU initiatives on semiconductors, but also funding from the France 2030 initiative. As part of the €30 billion ($30.7 billion) France 2030 investment initiative, France is committing nearly €6 billion ($6.5 billion) to the semiconductor industry, focusing primarily on the physical and electronics components to double the country's electronics production by 2030. This investment will go toward the creation of smaller chips, with the goal of reasserting France as a "leader in the field."

R&D Capacity: CEA-Leti is a government research center based in Grenoble and a major player in the international nanoelectronics sector. It has partnerships with various companies such as III-V Lab, Intel, Mapper, Soitec, and STMicroelectronics (ST) on a range of issues regarding the development and research of semiconductor technologies. The first-stage resources from the European Chips Act will go to major European research institutions. ST has an office in Tours that also works on R&D, engineering, processes, applications, and other business operations.

Fab Capacity: STMicroelectronics is the preeminent semiconductor vendor in France. The company operates two wafer fabs and the largest R&D center and produces up to 16 nm chips, providing notable production capacity. Its location in Grenoble has over 10,000 staff, and a manufacturing facility for automotive-grade chips in Rousset has over 4,000 staff. The company has a strong presence in automotive integrated circuits. ST is a key supplier to the German automotive industry. Besides fab capacity, France does have some back-end manufacturing capabilities. In 2017, UnitySC opened its operations in Grenoble, where it has approximately 10,000 square feet in cleanroom space and carries out its packaging operations.

Benefits and Risks: France benefits from robust macroeconomic stability and a well-developed financial system. Moreover, it is regarded as a prominent innovation hub. The 2021 IMD World Competitiveness Ranking places it at 29th overall; it is surpassed by its neighbors, the Netherlands and Germany. Regardless, it is the seventh-largest economy in the world in terms of GDP and eighth in total exports. France boasts the highest rate of public support for R&D among OECD countries. It is the top destination for international investment in Europe. Its well-educated population and renowned universities help generate a talented, well-equipped workforce.

Mainland France is close to the United Kingdom, Belgium, the Netherlands, and Germany. With its well-established infrastructure links, it is a key player in continental trade. Paris's Charles de Gaulle Airport processes the second-highest amount of airfreight in Europe, second only to the Frankfurt Airport. France is one of Europe's only silicon metal producers. Its overseas territories, stretching from French Polynesia to French Guiana, hold substantial amounts of mineral wealth. France stands to benefit from bauxite refining in French Guiana, which is crucial to extracting gallium. In addition, yet-untapped mineral reserves on the ocean floor of its maritime possessions in the Indo-Pacific would allow France to present itself as an alternative to China in supplying rare-earth minerals.

While France, along with Belgium and Germany, already has robust R&D infrastructure for next-generation semiconductors, it is creating plans to accelerate production. However, the United States Department of Commerce notes that France's regulations and government bureaucracy can sometimes restrain the French market.

ITALY

Italy has the third-largest economy in the European Union, with several large manufacturing sites for a diverse set of semiconductor components. In Italy, the automotive industry accounts for 6 percent of the GDP and employs 300,000 people, meaning the effects of semiconductor supply chain crunches are particularly pronounced for the country.

R&D Capacity: In June 2021, STMicroelectronics (ST) announced an agreement with the technological university, Politecnico di Milano, to create a research center on advanced materials for sensors. ST hopes to enable researchers and university faculty to collaborate on microelectromechanical systems technology and attract new academic talent. The company signed an agreement with the University of Catania in late 2021 to create a framework for enhanced education and research activities in power electronics. Italy is also the headquarters of Technoprobe, which has three research centers and 2,200 employees worldwide. Technoprobe specializes in testing solutions for chips, as well as the design, development, and production of probe cards. These allow for the testing of chips before they are individually packaged.

Fab Capacity: Italy is the second home of multinational STMicroelectronics, which has over 9,000 employees in the country. ST focuses on sensory and power technologies, automotive products, embedded processing solutions, and a broad range of segments. In reaction to high demand, ST plans to double its investments in 2022 to up to $3.6 billion. In Milan, ST has facilities with several fabrication lines, including a 300 mm fab. The company's Catania in Sicily site hosts two 200 mm fabrication facilities. In March 2022, the European Investment Bank announced it would provide ST a loan of €600 million ($628.7 million), which the firm will use for R&D and pilot production lines for advanced semiconductors. ST will use this investment primarily at two existing facilities in Italy and one in France. Following the announcement of this funding, French minister for the Economy, Finance, and Recovery Bruno Le Maire underscored that the primary goal of the funding is to accelerate French and Italian production of semiconductors, adding that "it is only by mastering this technology, that we will be able to safeguard the European Union's strategic independence."

Another significant player in the Italian semiconductor industry is Lfoundry, which runs an advanced 200 mm manufacturing fabrication site and proprietary technologies at 150 nm and 110 nm nodes. Lfoundry provides complementary metal-oxide semiconductor (CMOS) image sensors, or CIS, through CIS processes to 90 nm and backside illumination technology. In 2016, Lfoundry was acquired by Chinese Semiconductor Manufacturing International Corporation. PVA Italy is also a player, specializing in wafer plasma treatment systems and in crystal production plants for the photovoltaic industry and the semiconductor industry. NXP Italy in Milan manufactures devices for the automotive, industrial, and consumer and transaction/access segments.

Intel has been planning to expand into Italy with a facility for assembly, testing, and packaging, which would complement Intel investments in France and Germany. The Italian government has encouraged Intel to invest in the country. Turin and Catania are potential sites that Intel has considered for expansion.

Benefits and Risks: In some ways, Italy may not be an ideal partner for closer engagement on semiconductors with the United States. Among the identified potential European partners, Italy ranked last in both economic performance and government efficiency according to the 2021 IMD World Competitiveness Ranking, as well as in the World Economic Forum's competitiveness ranking. As a percentage of GDP, Italy also spends less on R&D than Belgium, the Netherlands, Germany, and France. Additionally, Italy has a less educated workforce than most of the European Union, with the second-lowest percentage of a tertiary-educated population among EU countries. Italy's political system is also relatively unstable compared to other western European nations, with coalition governments that are often short-lived.

Prime Minister Mario Draghi has taken steps to protect Italy's domestic semiconductor industry from Chinese competition. In April 2021, Draghi blocked a Chinese company from taking over an Italian semiconductor firm. This decision blocked Chinese company Shenzhen Investment Holdings from acquiring a 70 percent stake in Milan-based LPE. LPE produces components for power electronics applications. Draghi cited the ongoing semiconductor shortage as leading to slowdowns in the Italian automotive sector and said that semiconductors had thus become "a strategic sector" for the country. An actual or attempted Chinese acquisition of domestic industries is not inherently problematic, but the decision to allow a foreign takeover of a domestic business that is deemed to have strategic importance from both an economic and security perspective can change a government's calculation of risk.

Italy also has a complicated relationship with China, which affects its reliability as a partner in this strategic space. In 2019, Italy signed a memorandum of understanding supporting China's Belt and Road Initiative, against the warnings of European and U.S. leaders. Since the Draghi government took over in 2021, Italy has begun to reverse course and has reemphasized transatlantic relations while distancing itself from China. The Draghi government has vetoed bids by Chinese companies to acquire Italian firms on three different occasions, including once in the semiconductor industry as discussed above. Nonetheless, the back-and-forth nature of Italy's relationship with China causes concern when identifying potential long-term strategic partners.

However, there are benefits to partnering with Italy. A major benefit to closer collaboration with the country is the recent Intel investment. As mentioned above, the project intends primarily to build a large, state-of-the-art packaging facility, which has historically been the weak point in the European semiconductor supply chain. Thus, Italy may have to be included in any strategic planning out of necessity.

Draghi has been behind new momentum in Italy for European semiconductor production, saying in October 2021 that "governments need to fully commit to a European Union plan to increase the bloc's share of global semiconductor production to 20 percent by 2030." In March 2022, Draghi announced that Italy would spend €4 billion ($4.4 billion) to develop its domestic semiconductor industry. The Italian government has approved a new fund to allocate €150 million ($157.1 million) in 2022 and €500 million ($523.7 million) annually until 2030. The government is also in talks with Intel to nearshore part of its semiconductor supply chain to the country. It is estimated that Italian incentives for Intel, including favorable terms and public financing, will be worth €8 billion ($9 billion) over the next decade.

GERMANY

In 2020, Germany exported $6.5 billion in semiconductor devices, making it the fourth-largest exporter in the world. On the other hand, Germany is also the fourth-largest importer of semiconductor devices. Imports of semiconductors reached €5.7 billion ($6.3 billion) in 2019. In total, Germany accounts for €10.8 billion ($11.8 billion) of Europe's €33 billion ($36 billion) semiconductor market. Germany is key to semiconductor production due to its production of gases, specialty chemicals, and other consumables that play direct roles in fabrication and facility-cleaning materials. For example, Merck KGaA in Darmstadt produces specialty gases that are critical to chip production. Germany, like the rest of Europe, is challenged by the final step of the semiconductor value chain, back-end manufacturing. Germany's use of semiconductors is concentrated in consumer goods, such as automobiles and other high-end manufactured household goods. These include digital devices like cameras and household appliances such as dishwashers, which use standard rather than cutting-edge chips.

R&D Capacity: Intel has recently agreed to invest nearly €80 billion ($88 billion) in semiconductor production in the European Union, of which €17 billion ($18.6 billion) is slated for Germany, where the company plans to build a "leading-edge semiconductor fab mega-site." Companies such as Infineon, Carl Zeiss, and Zollner all have R&D operations in Germany. In 2020, Carl Zeiss employed approximately 1,300 people in R&D roles across Germany. The Fraunhofer Group for Microelectronics and the Leibniz Association are major players in international microelectronic R&D. Between the two groups, they have the largest cooperation for microelectronic R&D in Europe, over 2,000 research staff, and 12,000 square meters of cleanroom space.

Fab Capacity: Bosch has also been a major manufacturer of German semiconductor chips, including application-specific integrated circuits and power conductors. In December 2021, Bosch started large-scale production of silicon carbide semiconductors in its Reutlingen factory, where Bosch will manufacture the chips on 200 mm wafers to achieve "important economies of scale." This facility will enable Bosch to meet growing demand for chips used in both internet of things (IoT) and mobility applications. This new factory follows Bosch's 2021 expansion in Dresden. The semiconductor facility in Dresden is Bosch's first aIoT (AI with the internet of things), providing specialized chips for the automotive sector. Despite the expansion in semiconductor building capacity, it will likely not be sufficient to address supply chain issues in Europe, particularly amid sustained demand. Infineon is by far the largest semiconductor company in Germany. Originally part of Siemens, it spun off in 1999 and is now an independent company with revenues of over €11 billion ($13.2 billion) in 2021. Lantiq, a spin-off from Infineon Technologies, was a key supplier of broadband access and home networks technology, but it was acquired by Intel in 2015.

Benefits and Risks: Germany is an attractive partner for U.S. collaboration given its robust economy and stable political position in the European Union. Germany is the fourth-largest economy in the world and accounted for nearly a quarter of the EU GDP in 2020. Furthermore, Germany is an important global exporter, the third-largest after China and the United States. The United States imports many German goods and Germany is the United States' largest European trading partner. Germany is also the sixth-largest market for U.S. exports. According to the World Economic Forum's Global Competitiveness Index, in 2019, Germany ranked seventh in global competitiveness. Germany is advanced in research and innovation and has a pro-business climate. Germany has many established supply chain linkages and the policy to enforce due diligence. Furthermore, Germany has a strong industrial base, including its global leadership in the automotive industry.

Germany maintains a stable domestic government and historically has been one of the most politically influential countries in the European Union. The previous chancellor, Angela Merkel, established a leading role in the European Union for many years, but it is yet to be seen if the new chancellor, Olaf Scholz, will take on a similar role. Although it remains unclear as to what extent the new chancellor will continue Merkel's foreign policy approach to China or whether he will join Brussels in taking a harder line against Beijing, Germany's stable government makes it an attractive partner for continued U.S. partnership on semiconductors.

Germany is aiming to phase out coal and nuclear energy in favor of renewable sources. While this energy transition is desirable for the future, it could cause an increase in energy prices in the short term, affecting economic competitiveness.

Microelectronics was deemed an IPCEI by Article 107(3)(b) of the Treaty on the Functioning of the European Union. The article allowed five EU member states, including Germany, to allocate state aid to projects in microelectronics. This provided Germany with €1 billion ($1.01 billion) in funding for microelectronic industries. In December 2021, Germany formally notified the European Commission of a new IPCEI through which Germany will support transnational cooperation on microelectronics, such as semiconductors. With the new IPCEI for Microelectronics and Communication Technologies underway, Germany will benefit from €4.5 billion ($4.9 billion) in state aid and total investments of €15 billion ($16.5 billion). This is in addition to forthcoming funds from the European Chips Act, which will further enhance member state production capabilities. Other initiatives include Germany's Microelectronics Framework Program, launched by the German Federal Ministry of Education and Research last year, which emphasizes the importance of trustworthiness and sustainability in the supply chain. In addition, the EUREKA Clusters Program supports important research, development, and innovation topics with national authorities.

THE EUROPEAN UNION

Overall, the European Union is an attractive partner for closer collaboration with the United States on securing semiconductor GVCs. A particularly appealing and unique factor to investing in the European Union is its single market, which facilitates the free movement of goods, services, capital, and people. This makes it relatively easy for companies to invest across member states and to capitalize on local incentives and favorable business conditions. That Intel has deployed investments in France for R&D, Germany for production, and Italy for back-end manufacturing underscores the appeal of cooperating with the bloc on semiconductor GVCs. Furthermore, funding made available through both Brussels and member state governments helps increase the cohesion and resilience of semiconductor GVCs throughout the bloc. Other benefits the European Union offers in terms of supply chain resilience include geographic proximity to the United States and an existing close security relationship, including deepening cooperation on trade policies such as export controls.

When it comes to transatlantic cooperation regarding China—a strategic adversary to both parties, as well as a large and consistent customer—the relationship becomes more complicated. Overall, the European Union has taken a more moderate approach to China, seeking to increase market access for EU firms, while simultaneously adopting new trade defense and investment-screening tools, such as the EU anti-coercion instrument, intended to stem Chinese influence throughout Europe. Large European economies have an interest in maintaining positive relationships with Beijing due to its large consumer base, which maintains high demand for Germany's automobile industry, for example. In 2020, one in three German cars were sold in China. It remains to be seen whether China will continue to comply with international sanctions against Russia or whether a decision not to comply would force Brussels closer to Washington, D.C., in its approach to China.

Like the United States, the European Union has recently made significant changes to its export control and foreign investment policy. In September 2021, the European Union announced its new Export Control Regulation, which tightens control of dual-use items, strengthens critical supply chains, and protects human rights. It also seeks to enhance cohesion among member states regarding export control policy, including by providing capacity-building and training services for licensing and enforcement programs.

Outside of the Wassenaar Arrangement, the TTC has bolstered EU-U.S. collaboration on export controls following the Russian invasion of Ukraine. The TTC has provided diplomats with clear communication channels through which to consult on urgent trade and security matters, including semiconductor supply chains. In the European Union, export controls have historically been a competency of member states, which vary by country. For example, Belgium delegates export licensing responsibility to its three regional states, adding complexity to an export control regime closely intertwined with—though distinct from—the European Commission. The joint statement released following the May 2022 ministerial lays out the transatlantic plan to cooperate more closely on semiconductor R&D, including increasing transparency on subsidies and developing an early warning system for semiconductor supply chain disruptions.

The Group of Seven (G7), currently under German leadership, has also proven adroit at navigating security and supply chain issues. The G7 responded swiftly to Russia's invasion of Ukraine, revoking Russia's most favored nation status and initiating sweeping sanctions on key Russian officials and business elites. Given the near impossibility of expelling Russia from the Wassenaar Arrangement and the improbability of Russia removing itself, multilateral cooperation on export controls is likely to occur through other frameworks, such as the G7, the TTC, and smaller plurilateral agreements. There is growing discussion about the need to capitalize on current momentum behind the international response to Russia by creating a new plurilateral arrangement for advanced technologies among allied countries. Possible participants include specific EU member states (such as France, Germany, and the Netherlands), Japan, South Korea, and potentially Taiwan. Such an architecture could either complement the Wassenaar Arrangement or potentially replace it.

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Quad Cooperation

INDIA

India, slated to become the world's most populous nation, is a major growth market for the semiconductor industry. In 2020, semiconductor consumption in India was worth 1.1 trillion rupees ($13.87 billion), significantly less than the €44 billion ($47.8 billion) consumed in Europe in 2020. However, consumption of semiconductors in India is expected to grow to $80–90 billion by 2030. Despite a large population and growing manufacturing base, India imports nearly 100 percent of its commercial semiconductor products. Most large multinational semiconductor companies such as Intel, Samsung, TSMC, NXP, Broadcom, and Micron have offices in India.

R&D Capacity: India has thus far specialized in the R&D and design phases of the semiconductor supply chain. A deep bench of highly skilled information technology and engineering workers, coupled with world-renowned public institutes of technology, enables India to specialize in R&D. This has led to several important public and private semiconductor R&D facilities in India. Since 2006, the Indian government has supported two Centers of Excellence in Nanoelectronics (CENs) at the Indian Institute of Science (IISc) in Bangalore and at the Indian Institute of Technology Bombay (IITB) in Mumbai. IISc's CEN hosts over 150 researchers across 14,000 square feet of cleanroom space, with the capacity to conduct leading-edge R&D at the 10 nm level. IITB's CEN hosts a nanofabrication facility that has limited fab capabilities for two-inch, four-inch, and eight-inch silicon wafers, though only for R&D purposes. In the private sector, several major semiconductor companies, such as Micron, Intel, Samsung, Texas Instruments, and Huawei, have R&D facilities in Bangalore, "India's Silicon Valley." For both Intel and Samsung, their facilities in Bangalore represent their largest R&D operations outside of their home countries.

According to the Indian Ministry of Electronics and Information Technology, over 500,000 Indian engineers are involved in designing 2,000 chips each year. This is the largest number of leading-edge chip designers outside of the United States. In India, most design output comes from very large-scale integration and electronic design automation (EDA). However, the United States continues to dominate by far in EDA scale and efficiency.

Fab Capacity: Despite its relatively strong R&D capabilities, India lags in semiconductor fabrication. India attempted to incentivize private fab construction in the late 2000s and 2010s, but it currently has only two fabs: the Society for Integrated Circuit Technology and Applied Research (SITAR) in Bengaluru and the Semi-Conductor Laboratory (SCL) outside of Chandigarh. SITAR can produce six-inch wafers, but not advanced nodes. SCL can fabricate 180 nm six-inch and eight-inch wafers. However, both facilities are government-run and primarily produce semiconductor products for defense and space uses, not for the Indian commercial market, though they do have onsite packaging and testing capacity. As a result, India produces no legacy or next-generation chips for export or domestic consumption, instead relying on imports of many of the products it researches and designs.

Benefits and Risks: The Indian government has taken several initiatives since December 2021 under its Semicon India Program, with an outlay of $10 billion to increase production of semiconductors. These include (a) a scheme for setting up semiconductor fabs, with financial support subject to fulfillment of certain conditions, infrastructure support, and a designation of a nodal agency for faster regulatory approvals; (b) a scheme for setting up display fabs, with similar fiscal and infrastructure support, and establishment of the nodal agency; (c) a scheme for setting up compound semiconductors and semiconductor assembly, testing, marking, and packaging, with a percentage of capital expenditure fiscally supported by the government on fulfillment of relevant criteria; and (d) the Design Linked Incentive Scheme composed of chip design infrastructure support, product design linked incentive, and deployment linked incentive. Through these incentives, the government is also looking to increase foreign investment in the sector. In February 2022, the government confirmed that it received applications from three companies for semiconductor fabs, two companies for display fabs, four companies for compound semiconductors and assembly, and three companies for design.

Unfortunately, systemic issues continue to restrain enthusiasm for closer collaboration with India. Ongoing water shortages, power outages, and transportation disincentivize new investment, particularly the construction of new production facilities. Furthermore, India has historically been reluctant to join the Western sanctions and export control regimes, aside from the Wassenaar Arrangement. Following the Russian invasion of Ukraine, India opted against joining the Western sanctions effort and abstained from a vote at the United Nations to condemn Russia's invasion, making India an outlier among the major powers. India's decision to maintain a middle line in global relations with China and Russia dilutes its attractiveness as a trusted partner for friend-shoring secure semiconductor supply chains.

JAPAN

Japan is the world's fourth-largest market for semiconductor manufacturing and equipment sales. The United States Department of Commerce estimates that Japan's semiconductor industry will grow to over $47 billion in 2022 after having grown more than 19 percent in 2021. In terms of global monthly wafer capacity, Japan accounts for roughly 15.8 percent of global supply. The effects of the ongoing semiconductor shortage have been particularly acute in Japan's automobile sector. In October 2021, for example, domestic automobile sales declined 31.3 percent due to the chip shortage.

Although Japan still has the most semiconductor factories in the world, these factories largely lag behind other more high-tech factories abroad and, thus, do not produce the type of cutting-edge semiconductor chips that are needed around the world. Japan's strength lies in its deep industrial expertise in semiconductor materials. For instance, in 2019, Sony semiconductors became a top global supplier through the production of camera image sensors. Other examples include Lasertech Corp., the world's sole manufacturer of equipment that tests stencils for the most advanced chip designs.

While Japan specializes in power semiconductors and NAND flash memory chips, it lags behind other Asian competitors—namely, South Korea and Taiwan—when it comes to the manufacture of next-generation, highly specialized chips. Furthermore, despite being home to 84 chip factories, Japan imports 64 percent of its chips, making it reliant on foreign producers and vulnerable to semiconductor supply chain disruptions.

One reason for this reliance is Japan's failure to embrace a horizontal production model of chips that gained favor in the early 2000s. The Japanese model instead focused on vertical integration, whereby companies like Toshiba, Fujitsu, and Hitachi produced chips solely for their own products. This model ultimately lost out to companies like TSMC, which focuses on producing chips for a wide range of uses and companies. Other reasons for the decline in Japanese chip making include the industry's delay in embracing digitalization and a lack of public investment.

R&D Capacity: Although Japanese R&D expenditure remains relatively high at roughly 3 percent of the GDP, it continues to lag behind competitors when it comes to industrial innovation. In May 2021, TSMC announced it would open an R&D facility in Japan to develop cutting-edge semiconductor technology. The cost of the new project is anticipated to be roughly $338 million, of which the Japanese government will subsidize about half.

Fab Capacity: The 1980s were marked by lithography asymmetry between the United States and Japan, though Japan became dominant as the country's indigenous semiconductor market expanded. Japanese manufacturing is not as strong as it was in the 1980s and 1990s. Statistics from Japan's Ministry of Economy, Trade, and Industry (METI) show that the Japanese share of the world's semiconductor market shrank from 50 percent in 1990 to 10 percent today. One factor that affected Japan's domestic semiconductor market was the entry into the U.S.-Japan Semiconductor Agreement in 1986. The agreement called for antidumping guarantees, along with a 20 percent market share provision meant to open the Japanese market to foreign producers over a five-year time frame.

Another factor that restrained Japanese growth of the indigenous semiconductor industry is that Japanese companies invested in dynamic random access memory (DRAM), rather than advanced logic chips. Intense competition from Korean firms in DRAM memory led Japanese companies to double down on DRAM-related skills and accelerate production of DRAM memory chips, moving the Japanese market further away from a focus on computing power. Around the time this decision was made, U.S. markets shifted their focus to computing power rather than memory. Advanced computation capabilities have national security implications, including applications in quantum computing efforts and military advancements, meaning that investments in advanced computing—rather than memory chips—can facilitate increased strategic independence over time and reduce reliance on foreign producers for critical technologies.

Benefits and Risks: In June 2021, METI announced the creation of its "Strategy for Semiconductors and the Digital Industry." A core goal of the new strategy is to maintain Japan's modest 10 percent of the global market share of semiconductors by 2030. Maintaining that 10 percent market share will cost an estimated $38 billion. In recognizing the weaknesses in its semiconductor supply chain, the government is working to help companies enhance production of chips, large-capacity batteries, and other key materials through subsidy programs. In addition to the public funding boost for Japan's semiconductor industry, TSMC has announced it will spend $7 billion to open a new production facility in southern Japan, expected to be completed in 2024.

In May 2022, the United States and Japan held the first ministerial meeting of the Japan-U.S. Commercial and Industrial Partnership, at which the parties agreed to develop "Basic Principles on Semiconductor Cooperation" to be coordinated by the United States Department of Commerce and METI. At the leadership summit of the two heads of state in late May, the parties announced efforts "to cooperate on diversifying semiconductor production capacity, increasing transparency, coordinating emergency response on shortages, and strengthening semiconductor R&D and workforce development." The United States and Japan are also working toward creating a working group to facilitate joint research into state-of-the-art semiconductors. They also agreed to establish a "Work Plan on Export Control Cooperation." These joint initiatives seek to enhance semiconductor supply chain resiliency while limiting the proliferation of sensitive dual-use technologies.

AUSTRALIA

Aside from producing some chips used in Wi-Fi and the Mars Rover, Australia is largely a consumer of chips and lacks the direction and commercial will to reenter the strategic semiconductor sector.

R&D Capacity: Australia does have potential strengths based on its history and market dynamics. It has world-class design capability in radio frequency, millimeter wave, photonics, and radar. Australia is also fortunate to have abundant and underdeveloped silica deposits, a critical compound for wafers. Its history of successful mineral exploration and extraction could accelerate the development of domestic silica mines. Alternatively, Australia's robust materials science, academic, and R&D capabilities are also well positioned to explore silica substitutes.

Fab Capacity: Australian companies involved in the semiconductor industry are small and scattered, and have different technological requirements for semiconductor development. Some of the biggest challenges involved in growing the industry are deciding where to build a foundry and figuring out how to grow the ecosystem. A manufacturing plant will not automatically turn the switch on for the industry. There are currently no large Australian companies whose core business activity is participation in the semiconductor design, development, and production value chain.

Benefits and Risks: There are several downside risks for large Australian semiconductor producers. Risks include a lack of historical experience in the sector and a lack of incentives for capital investors, which lack the impetus to launch the typical 5–10-year investment cycle needed to establish the industry. Australian investors are also reluctant to accelerate investments due to the regional competition from Taiwan, as well as a crowded global market.

THE QUADRILATERAL SECURITY DIALOGUE

When Quad countries convened in person for the first time in September 2021, the joint statement highlighted that the partners are working together to map semiconductor supply chains. The parties affirmed "positive commitment to resilient, diverse, and secure supply chains of critical technologies, recognizing the importance of government support measures and policies that are transparent and market-oriented." Joint efforts to build more resilient supply chains and combat nonmarket economic practices represent an enhanced level of coordination against China. Australia and Japan have joined efforts to restrict trade with Russia, but India's reluctance to join the coordinated response weakens the Quad's general position vis-à-vis Europe when it comes to friend-shoring semiconductor supply chains. Overall, it remains to be seen which tangible results will materialize from Quad partnerships.

Recommendations and Conclusion

Semiconductor GVCs are inherently complex in nature, meaning there are distinct limitations to what the United States can accomplish unilaterally. Onshoring of semiconductor supply chains is not feasible in the short term. In the long term, onshoring would raise prices, reduce efficiency, and dampen long-term U.S. competitiveness. Thus emerges the need for an affirmative agenda for semiconductor supply chains among allies.

One fundamental recommendation from interviews conducted for this research project centered around the need to identify tangible goals that will enable governments and the private sector to bolster semiconductor supply chain resiliency. Another recommendation that emerged from this research is the need for the U.S. government to promulgate consistent, predictable policies—particularly related to trade—including collaborating to create a new Information Technology Agreement (ITA) to reduce tariffs on additional ICT goods. Overall, interviewees stressed that the government should avoid blanket export controls that risk dampening investment in allied semiconductor industries and should consider the creation of a new mini-export control regime that could function similarly to the Wassenaar Arrangement. These findings, coupled with an evaluation of the benefits and drawbacks of working with specific countries, make closer cooperation particularly enticing with Belgium, Germany, Japan, and the Netherlands.

First, the United States, in concert with close allies, must identify the goals it seeks to achieve by bolstering efforts to friend-shore supply chains, while simultaneously seeking to dampen the ability of foreign adversaries to gain a competitive edge over next-generation chips. Allied countries need to determine whether their policies are primarily motivated by pandemic-induced supply chain crunches or whether these policies constitute an inherently negative agenda that is reactionary to adversaries' technological advancements. Once allies have an affirmative agenda, it will fall on countries to collaborate on smart, targeted investments that bolster innovation. These investments should seek to mitigate "small batch" problems that restrain the ability of startups to obtain prototypes of new semiconductors. These policies should also seek to avoid a subsidy war in which multi-government spending results in significant overcapacity.

In addition to leading efforts in building an affirmative semiconductor supply chain agenda, the United States should work with close allies to promulgate consistent, predictable policies. These include increased certainty about the application of tariffs that affect the semiconductor industry. For example, the USTR **finding** that Vietnam's currency manipulation was actionable under Section 301, coupled with labor shortages and Covid-19 regulations, created an environment that led to Samsung relocating some of its production to Indonesia and India. Such a move was costly for the company and an option only available to large firms with adequate agility.

The United States should also work with allies to create a new **ITA** with the goal of reducing tariffs on additional ICT goods. Technology changes quickly in this sector, and the first two ITA iterations do not cover newly developed products and technologies. A new ITA would represent a step forward in continuing liberalization throughout the ICT sector.

Promulgating consistent trade policy with allies is also crucial. Moreover, the United States should avoid blanket export controls that risk dampening investment in allied semiconductor industries, as well as restraining the ability of U.S. firms to invest in next-generation R&D efforts. If the United States chooses to pursue a more integrated approach to semiconductor supply chains with the European Union and Japan, this decision is likely to have a fundamental impact on existing international export control architecture, potentially leading to the creation of a new framework. The United States should therefore also more seriously consider the creation of a mini-regime, which could function more similarly to the Wassenaar Arrangement. A new mini-regime could also enhance information sharing among allies and increase transparency related to government spending on semiconductors.

It is very unlikely that even a highly coordinated mini-regime will prevent China from obtaining critical semiconductor technology in the long run. However, an effective regime can delay that inevitability and buy time for like-minded countries to invest in and create the next generation of semiconductors, increasing tech sector independence and resiliency. Furthermore, a new mini-regime could capitalize on current momentum among a group of 38 countries to coordinate and codify new technology controls.

Given plans in the European Union to fortify and expand its semiconductor capabilities, the United States should work with Brussels in the TTC to institutionalize closer collaboration. The parties should work together to implement frameworks that would facilitate surge capacity for production, including an assistance agreement to ramp up production in cases of supply chain disruptions. While redundancy in production can be helpful in certain instances—for example to ensure an adequate supply of chips used in automobiles—with limited financial resources, the parties should seek to avoid duplicative efforts on next-generation R&D. Overall, increased semiconductor cooperation presents the United States and the European Union with a unique opportunity to build a positive agenda that cements its leadership in critical technologies.

While the United States has long maintained export controls in the semiconductors sector, particularly on chip manufacturing equipment, the Russian invasion of Ukraine and deteriorating relations with China have made national security a much more important part of the trade policy debate. The result is that companies are forced to rethink how they make location decisions. Supply chain management historically has centered around price, quality, and delivery. Now, in this sector in particular, governments have effectively added security and compliance with government policies and regulations as an important additional variable that affects companies' supply chain location strategies. In an already complex industry operating in an environment of growing geopolitical tensions, cooperation with allies becomes even more important for the private sector and governments alike.

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For both the United States and foreign partners, governments need to identify—and then implement policy based on—where they want to lead and where they can afford to follow. Thus emerges an inherent need to develop an affirmative strategy that identifies end goals and leverages multilateral frameworks as an avenue for achieving those goals. Creating a stronghold over chokepoints throughout semiconductor GVCs affects consumer markets and national security capabilities, thus amounting to geopolitical power.

Based on an assessment of what EU and Quad countries are currently producing, as well as their alignment with U.S. export control policy, the best candidates for friend-shoring U.S. semiconductor supply chains are EU member states and Japan. Within the European Union, the best candidates from a supply chain security perspective, both in terms of national security considerations and overall supply chain resiliency, are Belgium, Germany, and the Netherlands. Each has an educated population, a relatively open immigration system that can attract foreign talent, and an existing close relationship with the United States on issues of national security.

> *For both the United States and foreign partners, governments need to identify—and then implement policy based on—where they want to lead and where they can afford to follow.*

Overall, disruptions throughout the semiconductor GVC are likely to persist, making it a more urgent matter for governments and the private sector to minimize ongoing disruptions. The Russian invasion of Ukraine could prolong these trade disturbances and could also usher in a more fractured global trading system in which China and Russia become closer and liberal democracies band together, leaving countries like India awkwardly in the middle. Mounting tension between authoritarian and democratic states, coupled with an injection of social policy into trade agendas, is likely to reshuffle semiconductor GVCs, particularly as the United States reconsiders what qualifies countries to maintain trusted trading partner status. ■

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