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An Allied Approach to Semiconductor Leadership

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Many countries rightly seek to maximize their value added in the global semiconductor industry. But like-minded allied nations can also advance their leadership collectively by collaborating on technology and ecosystem development, intellectual property, and trade liberalization.

KEY TAKEAWAYS

- The semiconductor sector constitutes one of today's most important industries, providing the core technology that powers the modern digital world and spurs innovation and productivity across virtually every sector of the economy.
- The increasing expense, complexity, and scale required to innovate and manufacture semiconductors means that no single nation or enterprise can go it alone. In the face of challenges from China, allied cooperation in semiconductors is critical.
- Successful semiconductor innovation depends on scientists, researchers, and engineers working together internationally across companies, universities, government agencies, research institutions, and public-private research consortia.
- Each segment of the global semiconductor value chain has, on average, enterprises from 25 countries involved directly, and enterprises from 23 countries in support functions.
- Some nations have focused on building their domestic semiconductor ecosystems, but the U.S. industry's track record of success shows how to effectively leverage global supply chains for mutual benefit.
- Countries that would seek self-sufficiency in the sector, especially through unfair mercantilist means, risk inflicting considerable damage on the industry, slowing global semiconductor innovation.
- The United States should increase funding for collaborative, pre-competitive R&D and incentives for greater domestic production.

Semiconductors represent one of the world's most important industries, the core technology that powers the modern digital world and empowers innovation and productivity growth across every industry. In turn, the evolution of global value chains has enabled the industry to sustain its relentless, multi-decades drive to produce ever-more powerful integrated circuits at ever-lower costs—a dynamic captured in Moore's Law: the notion that the number of transistors on a microchip doubles about every two years, effectively meaning a semiconductor's capability in terms of speed and processing is doubled, even though its cost is halved. However, recognizing semiconductors' foundational role in the modern global economy, and their importance to national security, an increasing number of nations are seeking to capture as much value as possible from the industry, whether from semiconductor research and development (R&D); design; fabrication; or assembly, test, and packaging (ATP).

While national, including U.S., policies to spur semiconductor R&D and production are important, it's also important to recognize that self-sufficiency cannot and should not be the goal. The increasing expense, complexity, and scale required to innovate and manufacture semiconductors means that no single nation can afford to go it alone. However, there exists an opportunity and a need for a like-minded set of nations committed to open trade and fair economic competition to collaborate in ways that collectively empower the competitiveness of their semiconductor industries.

This report begins by examining the global semiconductor industry, including the rise of semiconductor global value chains, and by examining nations' semiconductor competitiveness strategies. It then examines how a community of allied nations can work together across four areas—by working collaboratively on semiconductor technology development, ecosystem support, and technology protection, as well as by developing supportive trade rules and regimes—to collectively enhance the competitiveness and innovation potential of their respective semiconductor industries and the industry globally.

The report makes the following policy recommendations:

Coordinated Technology Development

- Establish Manufacturing USA Institute(s) supporting semiconductor industry innovation—in activities including R&D, manufacturing, and packaging—and invite participation by semiconductor enterprises headquartered in like-minded nations.
- Expand international cooperation in semiconductor sector public-private partnerships.
- The United States and like-minded nations should increase funding for collaborative, pre-competitive R&D efforts, and ensure that there is reciprocal opportunity for semiconductor enterprises from like-minded nations to participate in such consortia.
- The U.S. government should work to more effectively coordinate the semiconductor R&D programs being conducted across various government agencies.
- The U.S. government should explore authorizing more-flexible federal contracting guidelines, such as a relaxation of Federal Acquisition Regulations, or allowing greater use of other transactional authority vehicles, in order to increase the commercialization potential of federally funded semiconductor R&D research programs.

- The U.S. government should invite other allied nations to co-invest in semiconductor moonshots, with resulting intellectual property (IP) and technical discoveries shared at levels proportionate to national mutual investment.
- The United States should explore additional opportunities to enroll peers from allied nations in the trusted foundries programs, with allied nations acting reciprocally for their related programs.
- Like-minded nations should amend their procurement guidelines by adding a fourth key pillar—security—in addition to the traditional standards of price, cost, and quality.

Coordinated Semiconductor Ecosystem Development

- Like-minded nations should continue to advocate for open standards-development processes, both as they relate to semiconductors specifically and to the vast panoply of downstream digital technologies fundamentally predicated on semiconductors, such as 5G, artificial intelligence (AI), the Internet of Things, and autonomous vehicles.
- Like-minded nations and enterprises therein should collaborate to develop a fundamentally more-secure computing infrastructure.

Coordinated Technology Protection

Export Controls

- U.S. export controls must be regularly updated to reflect the global state of play in semiconductor industries, such that controls do not preclude U.S. enterprises' ability to sell goods that are on a technical par with commercially available goods and services from foreign competitors.
- Any emerging technologies that are ultimately deemed to meet the statutory standards for export controls should be designated as such only in cases of exclusive development and availability within the U.S. market—and the controls should be removed if and when that exclusivity no longer exists.
- The United States should eschew the application of unilateral export controls and seek to develop a more ambitious and effective plurilateral approach to promulgate export controls among like-minded nations that have indigenous semiconductor production capacity.
- Congress should expand the remit and funding for the Export Control and Related Border Security (EXBS) Program at the U.S. Department of State.
- At the 2020 Multilateral Action on Sensitive Technologies (MAST) conference, scheduled for September 2020, the United States should consider introducing a plurilateral approach to advanced-technology export controls.

Foreign Investment Screening

- The United States should work with like-minded nations to align foreign investment screening practices and to exchange information when it appears other nations are trying to use unfair practices in making foreign investments, such as heavily state-subsidized, state-owned enterprises (SOEs) attempting to purchase foreign enterprises in advanced-technology industries.

- The United States should continue to work with like-minded nations to coordinate investment screening procedures, and it should consider expanding its list of "excepted foreign states" to include countries such as France, Germany, the Netherlands, Italy, Japan, and South Korea (among others).

Cataloging and Combatting Foreign Technology and Intellectual Property Theft

- Like-minded nations should develop a comprehensive list of enterprises and individuals who have attempted or affected IP theft, and develop mechanisms to restrict such firms and individuals from competing in like-minded nations' markets.
- Like-minded nations should enhance information-sharing efforts to combat foreign economic espionage and IP/technology/trade secret theft.
- The United States should lead like-minded nations in developing stronger information-sharing mechanisms focused on combatting state-sponsored economic espionage in advanced-technology industries.
- The United States should continue to work with like-minded nations to strengthen their trade secret protection regimes.
- The United States and other like-minded nations should continue to include robust trade secret protections, and penalties for willful large-scale commercial trade secret theft, in trade agreements they pursue.

Supportive Trade Policies, Regimes, and Practices

- Elevate the imprimatur and stature of the World Semiconductor Council (WSC).
- Expand the Information Technology Agreement (ITA).
- Maintain the World Trade Organization (WTO) e-commerce customs duty moratorium.
- With like-minded nations, join and expand the Comprehensive and Progressive Trans-Pacific Partnership (CPTPP) Agreement.
- Expand subsidies disciplines at the WTO.
- Insist on market access reciprocity in digital government procurement activity.
- Consider forming a Global Strategic Supply Chain Alliance (GSSCA).
- Develop an allied approach to expand market-based trade approaches in the Indo-Pacific region.

THE GLOBAL SEMICONDUCTOR INDUSTRY

The term "semiconductor" actually refers to a solid substance—such as silicon or geranium—which has electrical conductivity properties allowing it to be used either as a conductor or an insulator. In 1956, Bell Labs' John Bardeen, Walter Brattain, and William Shockley won a Nobel Prize for their 1947 invention of the transistor, a semiconductor device used to amplify or switch electronic signals and electrical power. In the mid-1950s, Jack Kilby at Texas Instruments and Robert Noyce and a team of researchers at Fairchild Semiconductor pioneered the integrated circuit, placing multiple transistors on a single flat piece of semiconductor material, giving rise to the modern visage of a "semiconductor chip." But modern semiconductors are a far cry from those invented by the early pioneers; today, they contain billions of transistors on a chip the size of a square centimeter, circuits are measured at the nanoscale ("nm," a unit of length equal to one millionth of a meter), and the very newest semiconductor fabrication facilities are producing semiconductors at 5 nm and 3 nm scales.[1] Leading-edge semiconductors contain transistors that are 10,000 times thinner than a human hair.

The increasing miniaturization of semiconductors alongside performance enhancements in both processing capacity and speeds as well as power efficiency lie at the core of every single information and communications technology (ICT) product. It's principally the evolution of semiconductors that explains the ever-increasing capability at an ever-decreasing relative price of digital products—everything from cells phone costing $4,000 in 1983 to just a few hundred dollars today to the cost of personal genome sequencing dropping from $2.7 billion to $300 over the past 20 years to the emergence of new "G's" in wireless communications about every decade.[2]

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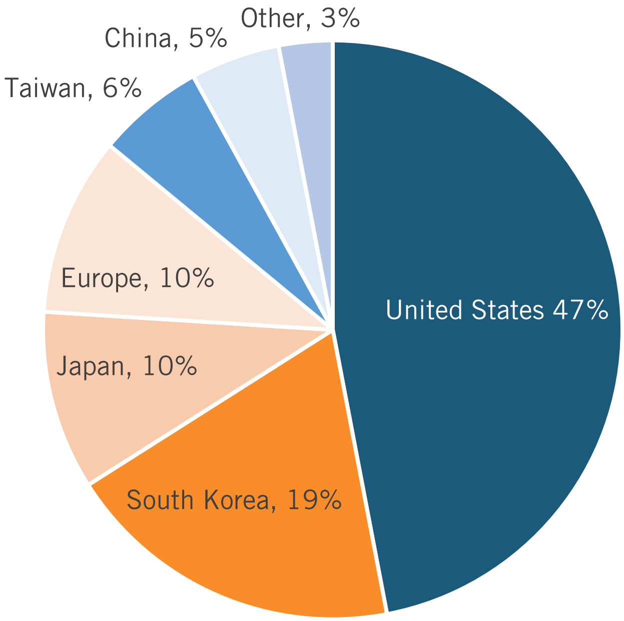
Harvard economist Jon Samuels estimated that total factor productivity in the U.S. semiconductor sector grew at close to 9 percent over the period from 1960 to 2007 (25 times the rate for the overall economy) and to have accounted for nearly 30 percent of the United States' aggregate economic innovation over this period.[3] In terms of industry-specific contributions, from 1960 to 2007, semiconductors accounted for about 37 percent of the growth in the U.S. communications equipment manufacturing industry, 14 percent of the expansion of the electrical equipment and appliances sector, and 24 percent of the growth in output among other electronic products.[4] Oxford Economics estimated that the semiconductor industry helps create $7 trillion in global economic activity and is directly responsible for $2.7 trillion in total annual global gross domestic product (GDP).[5] And with the digital economy now accounting for nearly one-quarter of global GDP, semiconductors power the future of digitalization, underpinning everything from AI, cloud computing, and the Internet of Things to advanced wireless networks, smart grids, smart buildings, and smart cities, and even the next generation of quantum computing.[6]

The semiconductor industry itself represents a $470 billion highly globalized industry (expected to become a $730 billion industry by 2026) that shipped over 1 trillion semiconductors for the first time ever in 2019, with some of these processors containing over 30 billion transistors.[7]

In 2019, U.S.-headquartered semiconductor enterprises held a 47 percent market share of global semiconductor industry sales, followed by South Korean firms with 19 percent, Japanese and European firms each with 10 percent, Taiwanese firms with 6 percent, and Chinese enterprises with 5 percent. (See figure 1.)

Figure 1: 2019 Global semiconductor industry sales market share[8]



However, the picture is very different when it comes to value added (the value of actual production in a nation). In 2016 (the most-recent year for which data is available), China produced $120 billion in value added, compared with $83 billion for the United States, $55.6 billion for Taiwan, and $39 billion for South Korea. (See figure 2.) U.S. value added in the sector peaked at $91.3 billion in 2011 (values in nominal dollars). China's value added in the sector increased three-fold from 2007 to 2016. In terms of share of global value added in the semiconductor industry, from 2001 to 2016, China's grew almost four-fold, from 8 to 31 percent, while the United States' share fell from 28 to 22 percent, and Japan's share fell by over two-thirds, from 30 to 8 percent. Taiwan and South Korea both saw their shares double or almost so, with Taiwan's share growing from 8 to 15 percent and South Korea's growing from 5 to 10 percent. Germany and Malaysia maintained shares of 2 percent each. (See figure 3.)

Figure 2: Value added ($ billions) of semiconductor industry by economy, 2001–2016[9]

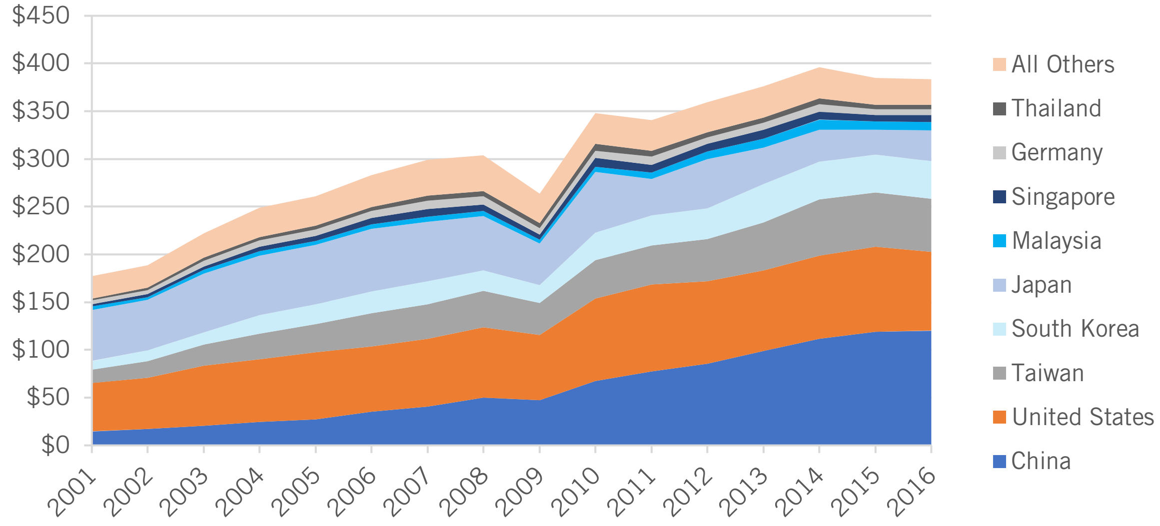
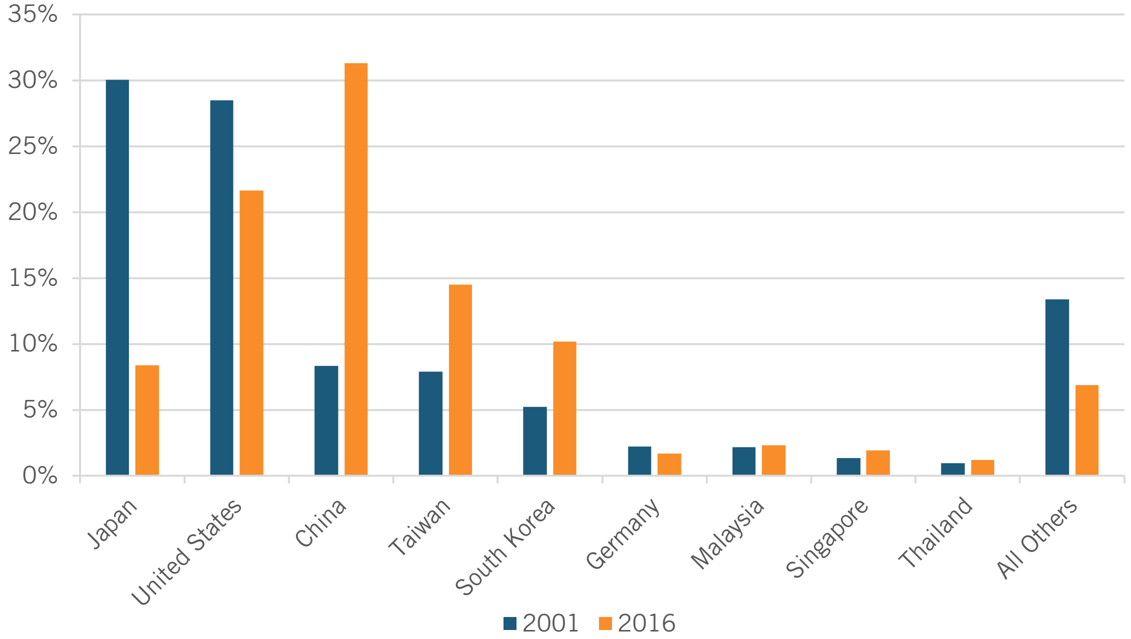


Figure 3: Country share of value added in global semiconductor industry, 2001 and 2016[10]



According to Organization for Economic Cooperation and Development (OECD) data, in 2018, China exported $138 billion in semiconductors, Taiwan $111 billion, South Korea $92 billion, Singapore $87 billion, the United States $53 billion, the EU-27 and United Kingdom combined $53 billion, and Japan $48 billion. (See figure 4.) In terms of trade balances, in 2019 (or the most recent year in which data is available for that country), Taiwan recorded a trade surplus of $54 billion, South Korea $47 billion, Japan $21 billion, Singapore $18 billion, and the United States $2 billion.[11] Conversely, in 2018, India recorded a $14 billion semiconductors trade deficit, the EU-27 countries and the United Kingdom an $18 billion one, and China a $235 billion deficit. (See figure 5.) However, it's important to note that while China's semiconductor trade deficit might appear quite substantial, the reality is that about half of these semiconductor imports were re-exported—with value added during assembly and manufacturing—from China as part of global production networks for cell phones, tablets, and other electronic products (one reason why China's semiconductors trade balance is no justification for it seeking autarky in semiconductor production).[12] China's trade deficit in semiconductors grew significantly during a time when its trade surplus in electronics goods (e.g., computers, cell phones, etc.) also grew significantly, accounting for 58 percent of the value of total exports.[13]

Figure 4: Semiconductor exports by country ($ billions), 2019 or most recent year available[14]

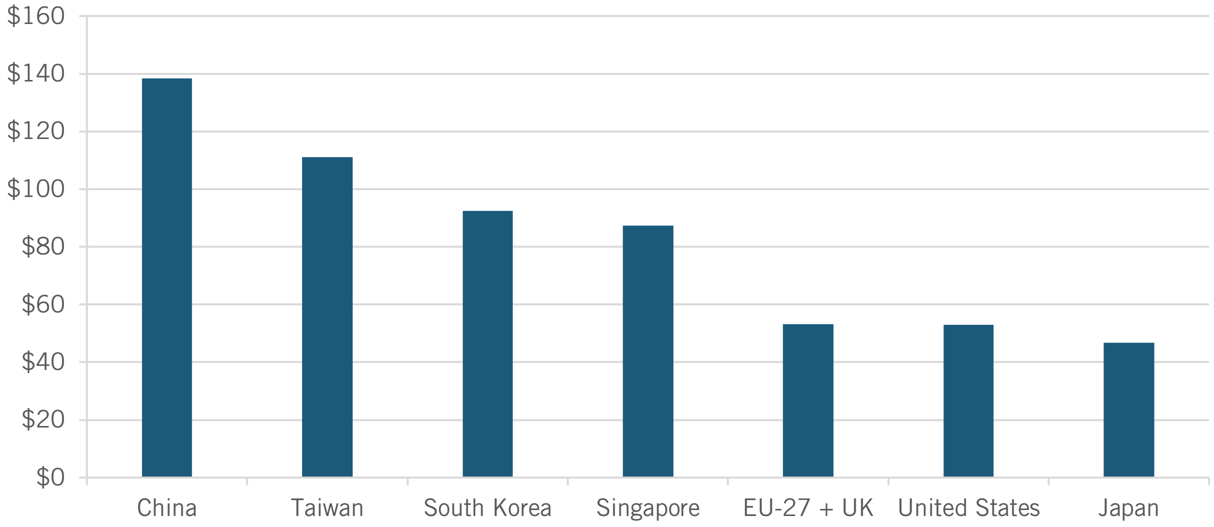
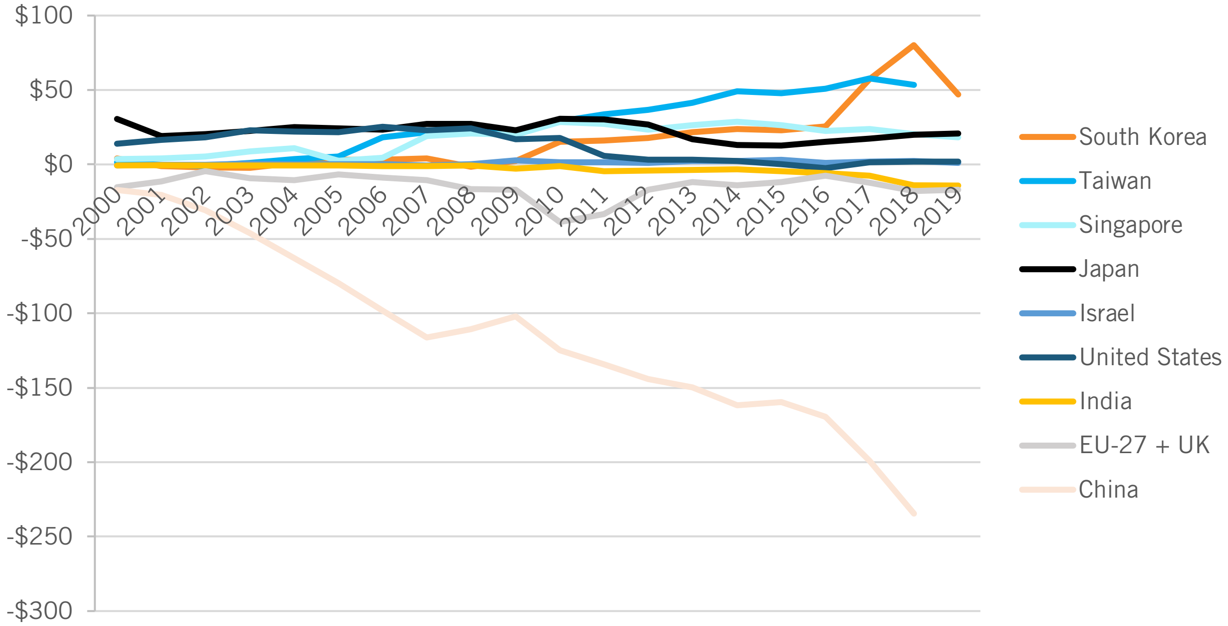


Figure 5: Semiconductor trade balances by nation, 2000–2019 ($ billions)[15]



Semiconductors represent the world's second-most R&D-intensive industry, after biopharmaceuticals. In 2018, U.S.-headquartered semiconductor companies invested 16.4 percent of their sales in R&D, compared with 15.3 percent on average for European-headquartered companies, 10.3 percent for Taiwanese firms, 8.4 percent for Japanese firms, 8.3

percent for Chinese companies, 7.7 percent for Korean firms, and 5.6 percent on average for semiconductor companies from all other nations.[16] (See figure 6.) Of the 12 most R&D-intensive semiconductor companies in the "2019 EU Industrial R&D Investment Scoreboard" report, half hail from the United States, and the top three most R&D-intensive companies are Qualcomm, which invests one-quarter of its revenues back into R&D annually, followed by Taiwan's MediaTek with 24.2 percent, and America's Advanced Micro Devices (AMD) with 22.1 percent. (See table 1.) In terms of actual investment, Samsung leads with €14.8 billion (approximately $17.6 billion) invested in R&D in 2019, followed by Intel with €11.8 billion ($13.7 billion).[17]

Figure 6: National semiconductor industry R&D intensity, 2019[18]

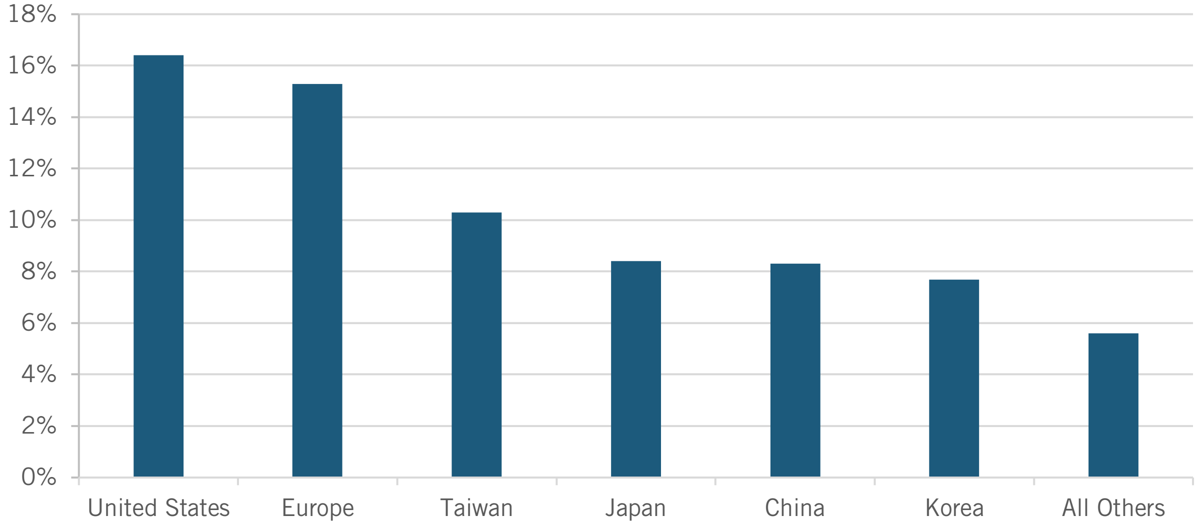
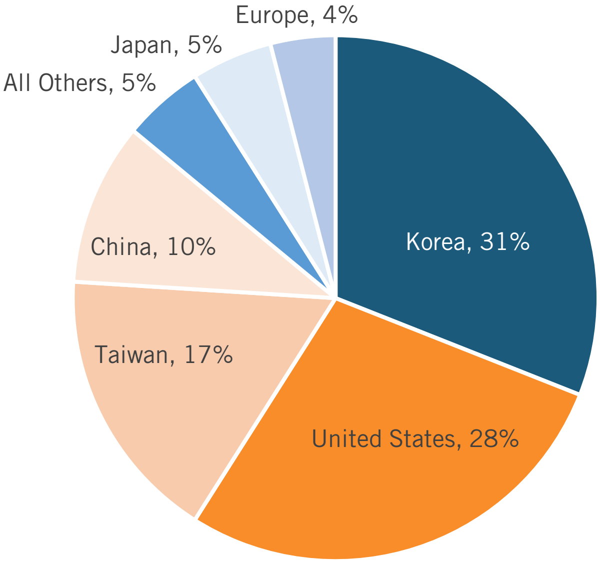


Table 1: Leading semiconductor investors on the 2019 EU Industrial R&D Investment Scoreboard[19]

Company	Headquarters	R&D Investment (Billions)	R&D Intensity (%)
Qualcomm	United States	€4.88	24.9
MediaTek	Taiwan	€1.64	24.2
AMD	United States	€1.25	22.1
NVIDIA	United States	€2.08	20.3
Intel	United States	€11.8	19.1
Analog Devices	United States	€1.02	18.8
Broadcom	United States	€3.29	18.1
NXP Semiconductors	The Netherlands	€1.48	18.1
Renesas Electronics	Japan	€1.01	16.9
Samsung	South Korea	€14.8	15.3
ST Microelectronics	Switzerland	€1.18	14.1
Huawei	China	€12.7	13.9
ASML	The Netherlands	€1.47	13.4

The industry is also highly capital intensive; in fact, the U.S. semiconductor industry's global gross capital expenditures (CapEx) reached $31.9 billion in 2019, making the industry's capital expenditures as a percentage of sales, at 12.5 percent, second only to America's alternative-energy sector.[20] In 2019, Korean-headquartered enterprises invested 31 percent of global CapEx in the sector, followed by U.S. companies with 28 percent, Taiwanese firms with 17 percent, Chinese firms with 10 percent, Japanese firms with 5 percent, and European firms with 4 percent. (See figure 7.)

Figure 7: Countries' headquartered-enterprise's percent share of global semiconductor industry capital expenditures, 2019[21]



The industry must be so R&D- and capital-intensive because innovating in the semiconductor industry requires increasingly complex chip designs at ever-smaller scales, especially if the industry is to keep up with the vaunted Moore's Law. And while some believed at the start of the last decade that the 28 nm threshold would herald the limit of Moore's Law, materials-engineering breakthroughs over the past decade in extreme ultraviolet lithography (EUV), etching, and thin-film deposition have brought the current industry frontier to 5 nm, with fairly clear visibility into the processes needed to get to 3 nm, 2 nm, and even 1 nm sizes.[22] As Dan Hutcheson, CEO and Chairman of VLSI Logic explains, even at the 7 nm level, today's semiconductors pack over 20 billion transistors on a single chip, working at tolerances that are 1/10th or smaller the size of the coronavirus.[23] Contributions from enterprises and researchers from a wide range of nations—including China, Germany, France, Japan, Taiwan, the Netherlands, South Korea, the United States, and the United Kingdom, among others—have been responsible for advances in improving device performance, lowering power consumption, and shrinking size, reflecting the truly global nature of the industry.

However, whereas innovation in the sector historically was largely about doubling the processing power of chips while reducing or maintaining costs, the locus of innovation today is shifting and expanding, moving beyond mere processing speed to include energy consumption, "systems on a chip" functionality, and entirely new forms of technology and computing architectures. For instance, Silicon Valley-based Tachyum is working on a new "universal processor" microchip that would consolidate three types of microprocessors—the central processing unit (CPU), graphics processing using (GPU), and a tensor processing unit (TPU)—into a single chip, potentially delivering significant processing speed and power-consumption benefits.[24]

Yet the expertise, capital, and scale needed to develop a new semiconductor design, or build a new semiconductor fab, is extremely high, and increasing. For instance, an April 2020 study finds that the number of researchers required to achieve Moore's Law (i.e., doubling of computer chip density) today is more than 18 times larger than the number required in the early 1970s.[25] This is one reason costs are increasing. In 2019, Taiwanese-manufacturer TSMC announced it would build a 5 nm fab in Arizona at a cost of $12 billion; in 2017, it had announced it was making plans to build a 3 nm fab in Taiwan at an anticipated cost of $20 billion.[26] As of 2020, it's estimated that building a new 14–16 nm fabs costs, on average, $13 billion; a 10 nm fab $15 billion; a 7 nm fab $18 billion; and a 5 nm fab $20 billion.[27] Reflective of the increasing cost of competing in the sector, whereas almost 30 companies manufactured integrated circuits at the leading-edge of technology 20 years ago, only 5 do so today (Intel, Samsung, TSMC, Micron, and SK Hynix).[28]

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Thus, the semiconductor industry represents a classic innovation-based industry characterized by extremely high fixed upfront costs of R&D and design, yet incremental costs of production (i.e., an individual chip comes off the production line at marginal cost). Moreover, the industry depends on one generation of innovation to finance investment in the next, so profits from the 10 nm fab beget the revenues to invest in the 7 nm fab, which make possible the 5 nm and 3 nm fabs of the future. As such, the ability of the global industry to sustain itself depends on several conditions attaining across the global economy. First, semiconductor companies need access to large global markets so they can amortize and recoup their costs across a single large global marketplace. Given the significant growth in fixed costs of R&D and capital equipment, the ability to access global markets is more important than it has ever been.

Second, semiconductor companies cannot face excess, non-market-based competition, such as governments pumping in hundreds of billions of dollars in subsidies, which unfairly disadvantages enterprises that are attempting to compete on genuinely market-based terms. In other words, if leading-edge companies cannot be assured that they can earn a reasonable, risk-adjusted rate of return on their investments—which is put in doubt by some governments such as China investing massive amounts of money to create a domestic semiconductor industry—then the leading companies will cut R&D and capital expenditures.

Third, because the industry fundamentally depends on knowledge, technology, and know-how, the international system must feature robust IP rights—including patents, trade secrets, and trademarks—for an extraordinary amount of the value is knowledge-based.[29] Again, if companies cannot retain that expensive IP, and it goes to competitors illegally and illicitly, their margins will go down, thereby reducing investment.

Finally, the industry relies on open and smoothly flowing global semiconductor value chains, as the following section elaborates.

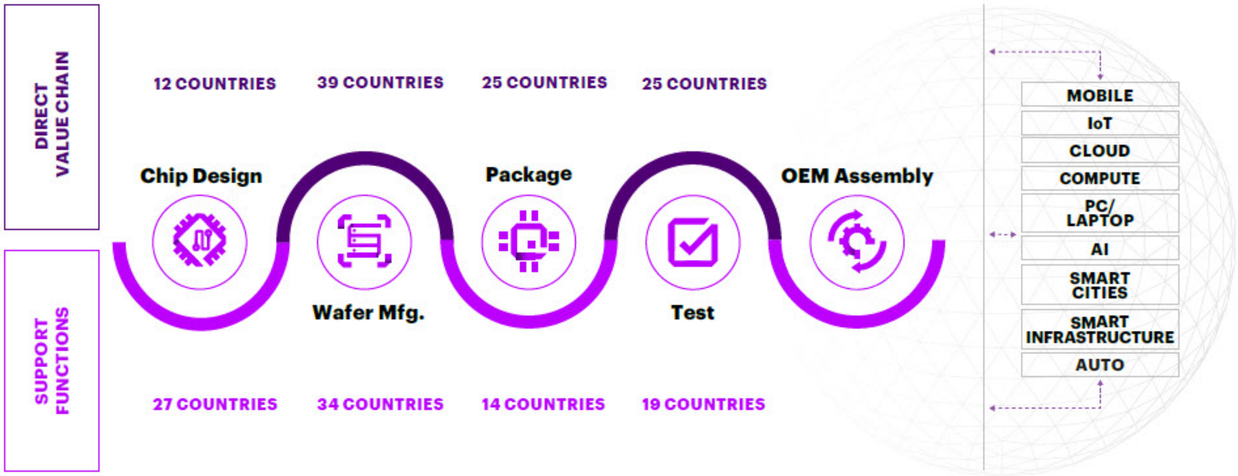
GLOBAL SEMICONDUCTOR VALUE CHAINS

The semiconductor industry has perhaps the most complex and geographically dispersed value chain of any industry in the world. In one stylized example, provided in the report "Beyond Borders: The Global Semiconductor Industry Value Chain," large silicon ingots might be produced and cut into silicon wafers (the material used for producing semiconductors) in Japan; those bare wafers shipped to the United States to be transformed into fab wafers and cut into dies, on which the functional integrated circuit is etched to make a semiconductor; those semiconductor chips then being shipped to a country, such as Malaysia or Vietnam, where the semiconductor chips go through the ATP process; those chips then being exported to a country, such as China, South Korea, or the United States, to be integrated into end products such as tablets, mobile phones, or servers; and then those final consumer end products exported to the world.[30] (See figure 8.) In fact, the typical production process toward a final electronics product can see the underlying semiconductors within it cross international borders 70 or more times in a process that takes over 100 days and includes 3 full trips around the world.[31] One reason for this globalized supply chain is that unlike some industries such as cement, or even automobiles, with a high weight (and volume) to value ratio, semiconductors are small and light—and the costs of moving them around the globe is minimal compared with their actual value.

Figure 8: Stylized example of semiconductor value chain[32]

Individual semiconductor companies have very complex supply chains. For instance, Intel has 15 wafer fabs in production worldwide at 10 locations, including 4 in the United States, and its supply chain comprises more than 11,000 suppliers in over 90 countries.[33] South Korea's Samsung identifies over 2,500 global suppliers, and SK Hynix has approximately 1,200 global suppliers.[34] Taiwan's TSMC operates 2 dozen fabs across multiple continents, producing 12 million wafers annually using 270 different silicon technologies that support 10,700 different customer products. Taiwan's TSMC is supported by more than 3,000 suppliers globally.

Figure 9: Number of countries participating in various phases of semiconductor manufacturing activity[35]



As noted, semiconductor R&D and chip design; semiconductor fabrication; and semiconductor ATP constitute the highest-level facets of the semiconductor production process. An estimated 90 percent of the value of a semiconductor chip is split evenly between the design and manufacturing phases, with the final 10 percent of the value provided through ATP activities.[36] A large number of countries field enterprises competing across multiple facets of semiconductor production. In fact, each segment of the semiconductor value chain has, on average, 25 countries involved in the direct supply chain and 23 countries involved in support functions. Over 12 countries have enterprises directly engaged in semiconductor chip design, 39 countries have at least 1 semiconductor fabrication facility, while over 25 countries have enterprises engaging in ATP activities.[37] (See figure 9.)

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Various countries and regions have carved out specific niches in global semiconductor supply chains. As the “Beyond Borders” report explains:

> Canada, European countries, and the United States tend to specialize in semiconductor design, along with high-end manufacturing. Japan, the United States, and some European countries specialize in supplying equipment and raw materials. China, Taiwan, Malaysia, and other Asian countries tend to specialize in manufacturing, assembling, testing, and packaging. Canada, China, Germany, India, Israel, Singapore, South Korea, the United Kingdom, and the United States are all major hubs for semiconductor R&D. Major semiconductor companies have located facilities in countries as far flung as Costa Rica, Latvia, Mexico, South Africa, and Vietnam.[38]

The internationalization of the semiconductor industry is also reflected by its leading players, with the 2019 top 4 global semiconductor sales leaders hailing from 3 different nations, led by America’s Intel ($69.8 billion in sales), South Korea’s Samsung ($55.6 billion), Taiwan’s TSMC

($34.7 billion), and South Korea's SK Hynix ($22 billion). (See table 2.) No Chinese company makes the top 15, and only 1, HiSilicon at 16, ranks in the top 25 (as of year-end 2019).

The three most-prevalent types of semiconductors are logic chips, memory (usually dynamic random-access memory (DRAM)) chips, and analog chips (those which generate a signal or transform signal characteristics, and are especially prevalent in automotive and audio applications). In 2019, the logic segment accounted for $107 billion in global sales, memory for $106 billion, and analog for $54 billion.[39] Intel is the world's leader in logic chip market share. Texas Instruments, Analog Devices, and Infineon account for the market leaders in the analog chip market, with market shares of 19, 10, and 7 percent, respectively.[40] Samsung, SK Hynix (both headquartered in South Korea), and Micron (United States) lead the world in DRAM production, accounting respectively for 44 percent, 29 percent, and 21 percent of global market share as of Q1 2020.[41]

Table 2: Top 15 2019 semiconductor global sales leaders[42]

Company	Headquarters	2019 Semiconductor Sales Revenues ($ millions)
Intel	United States	$69,832
Samsung	South Korea	$55,610
TSMC	Taiwan	$34,668
SK Hynix	South Korea	$22,886
Micron	United States	$19,960
Broadcom Inc.	United States	$17,370
Qualcomm	United States	$14,300
Texas Instruments	United States	$13,547
NVIDIA	United States	$10,514
Sony	Japan	$9,552
ST Microelectronics	Switzerland	$9,456
Infineon	Germany	$8,946
NXP Semiconductors	The Netherlands	$8,857
Kioxia	Japan	$8,715
MediaTek	Taiwan	$7,972

The globalization of semiconductor value chains has been driven by multiple factors, and produces manifold benefits. As Macher and Mowery elucidated in their report "Vertical Specialization and Industry Structure in High Technology Industries":

> The growth in vertical specialization in semiconductors since 1985 reflects the influence of both market-related and technological factors. Scale economies lowered production costs, expanding the range of potential end-user applications for semiconductors and creating additional opportunities for entry by vertically specialized firms. The increasing capital requirements of semiconductor

> manufacturing provided another impetus to vertical specialization, since these higher fixed costs made it necessary to produce large volumes of a limited array of semiconductor components in order to achieve lower unit costs. The design cycle for new semiconductor products also has become shorter and product lifecycles more uncertain, making it more difficult to determine whether demand for a single product will fully utilize the capacity of a fabrication facility that is devoted exclusively to a particular product and increasing the risks of investing in such "dedicated" capacity.[43]

As the "Beyond Borders" report expounds, for enterprises to compete successfully in various facets of the semiconductor supply chain thus "requires great specialization and offers a chance to add significant value. The supply chain thus becomes a value chain, with each activity contributing to the overall competitive edge of the final product."[44]

This is very different from "conventional" manufacturing industries wherein capital costs are nowhere near as high, and markets can support many producers in a particular industry, meaning that the odds of being able to have a significant share of suppliers located in a particular country, especially one with a large economy such as the United States, is much higher.

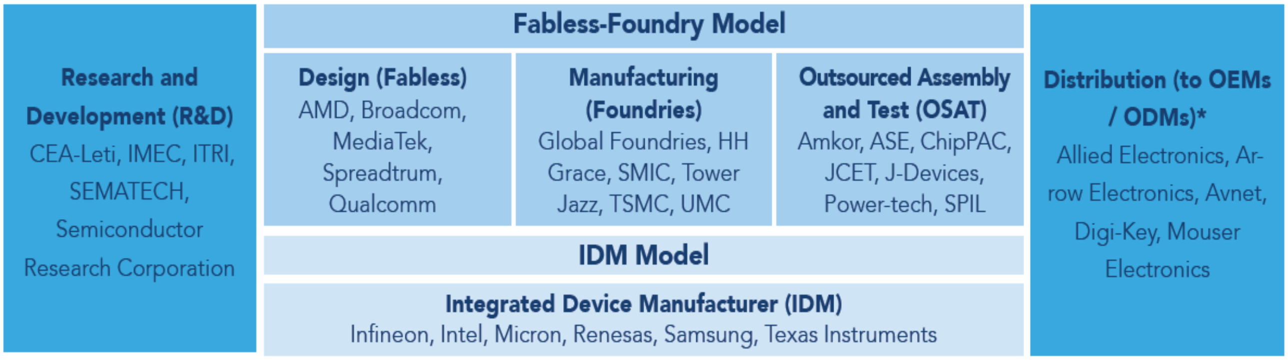
Perhaps most significantly, the globalization of supply chains has given rise to a wide variety of business models in the semiconductor industry. Historically (dating back to the 1950s and 1960s), the semiconductor industry consisted primarily of integrated device manufacturers (IDMs)—that is, firms which conducted all key facets of semiconductor manufacturing, especially design and fabrication, internally. Infineon, Intel, Micron, Renesas, Samsung, SK Hynix, and Texas Instruments remain leading IDM players today.

In 1987, Morris Chang founded TSMC, which pioneered the foundry business model, concentrating on contract manufacturing for fabless players that focus on designing semiconductors, often for application-specific purposes such as AI, wireless communications, or high-performance computing (HPC) uses. This essentially represents outsourced manufacturing, or "manufacturing as a service"—and it revolutionized the industry, giving rise to a host of new players including America's Global Foundries, China's Semiconductor Manufacturing International Corporation (SMIC), and Taiwan's United Microelectronics Corporation (UMC).

The advent of foundries in turn supported the rise of the fabless industry; that is, companies which focus on semiconductor chip design, such as (now fabless) AMD (chips for AI, HPC, and graphics), NVIDIA (graphics chips), and Qualcomm (5G and other wireless chips). Collectively, this is referred to as the "fabless-foundry" model.

Finally, outsourced ATP is performed by a number of global players, including Amkor (United States), ASE Technology (Malaysia), J-Devices (Japan), Power-Tech (China), and Siliconware Precision Industries (Taiwan). On the front end of the process are companies and consortia that focus on semiconductor R&D activity, such as CEA-Leti (France), Imec (Belgium), ITRI (Taiwan), SEMATECH (United States), and the Semiconductor Research Corporation (United States). (See figure 10.)

Figure 10: Operating models in the semiconductor industry[45]



Fabless-Foundry Model

Research and Development (R&D)
CEA-Leti, IMEC, ITRI, SEMATECH, Semiconductor Research Corporation

Design (Fabless)
AMD, Broadcom, MediaTek, Spreadtrum, Qualcomm

Manufacturing (Foundries)
Global Foundries, HH Grace, SMIC, Tower Jazz, TSMC, UMC

Outsourced Assembly and Test (OSAT)
Amkor, ASE, ChipPAC, JCET, J-Devices, Power-tech, SPIL

Distribution (to OEMs / ODMs)*
Allied Electronics, Arrow Electronics, Avnet, Digi-Key, Mouser Electronics

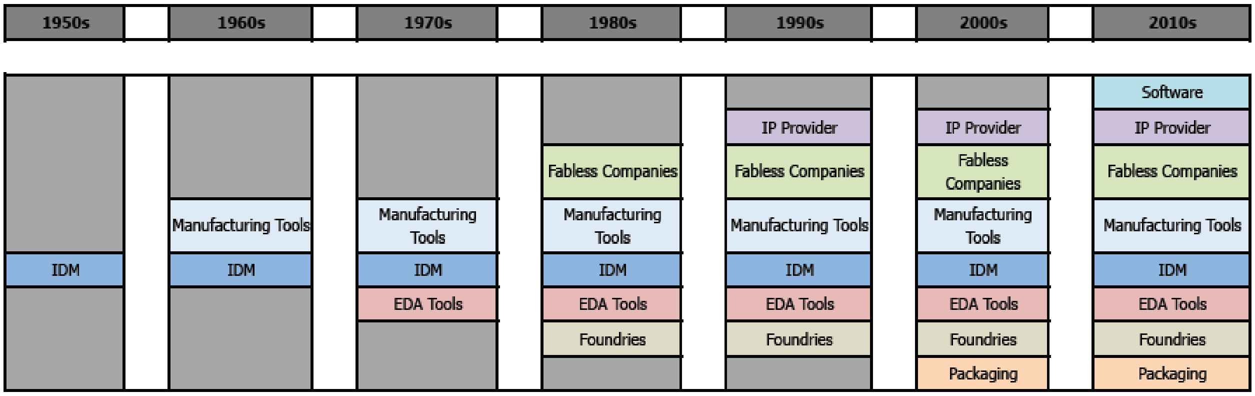
IDM Model

Integrated Device Manufacturer (IDM)
Infineon, Intel, Micron, Renesas, Samsung, Texas Instruments

Another set of companies, including Applied Materials (United States), ASML (the Netherlands), KLA Tencor (United States), and Lam Research (United States), manufacture the machines and tooling equipment that run semiconductor fabs. Finally, a number of enterprises, especially ones from Japan, South Korea, and Taiwan, manufacture chemicals and components essential to the semiconductor manufacturing process. For instance, fluorinated polyimides, a group of specialty polymers that provide physical strength and heat resistance, are produced by Daikin Chemical (Japan), DuPont (United States), Kaneka Asahi Kasei (Japan), and Taimide Technology (Taiwan). Photoresists are critical components that provide the patterns used to build micro-circuitry into semiconductors. The Japanese firms JSR Corporation, Shin-Etsu Chemical Company, Sumitomo Chemical, and Tokyo Ohka Kogyo Company manufacture photoresists, as do the Korean players Dongjin Semiconductor Company and Dongwoo Fine Chemicals. Portland, Oregon-based Inpria is the only U.S.-headquartered photoresists manufacturer, while European players have abandoned the field altogether.[46]

In short, the semiconductor ecosystem has evolved from fully integrated firms in the 1950s to a global set of firms that by the 2010s specialized in discrete activities such as R&D, design, machine tooling, components, foundries, assembly, test, and packaging. (See figure 11.)

Figure 11: Functional evolution of the semiconductor ecosystem (1950s–2010s)[47]



1950s	1960s	1970s	1980s	1990s	2000s	2010s
						Software
				IP Provider	IP Provider	IP Provider
			Fabless Companies	Fabless Companies	Fabless Companies	Fabless Companies
	Manufacturing Tools	Manufacturing Tools	Manufacturing Tools	Manufacturing Tools	Manufacturing Tools	Manufacturing Tools
IDM	IDM	IDM	IDM	IDM	IDM	IDM
		EDA Tools	EDA Tools	EDA Tools	EDA Tools	EDA Tools
			Foundries	Foundries	Foundries	Foundries
					Packaging	Packaging

And there are supply chains within semiconductor supply chains. Consider the supply chain for extreme ultraviolet lithography, centered on Dutch-based firm ASML, the world's leading manufacturer of high-end photolithographic machines, which uses light to etch integrated circuits into silicon wafers. ASML's global market share of photolithographic machines has doubled since 2005 to 62 percent (its competitors Canon and Nikon split the remainder).[48] But the EUV supply chain itself is global: German-based Carl Zeiss makes the lenses; VDL, a Dutch company, makes the robotic arms that feed wafers into the machine; and the light source comes from Cymer, a San Diego, California-based operation.[49] The technology underpinning photolithography today is the result of 15 years of research and some $20 billion in cumulative R&D investment made by multiple companies, including even Intel, Samsung, and TSMC, which have all co-financed some of ASML's R&D activities. Put simply, without the existence of global supply chains and the specialization they provide, the rapid evolution of EUV lithography technology would never have happened.

The ability to effectively leverage international supply chains can in part explain national leadership in semiconductor industries. Consider Japan and the United States. The fabless-foundry model has been key for the global—and especially the U.S.—semiconductor industry because it has enabled the industry to spread out the risks of its capital investments so that fabless design companies don't have to incur the risk of significant capital expenditures, or investing in the R&D for manufacturing process technologies. Back in the 1990s, the U.S. and Japanese semiconductor industries were at parity, with an equivalent level of global market share. Since then, the United States (i.e., U.S.-headquartered enterprises) has retained about half the global semiconductor market, while Japan's share has fallen to less than 10 percent. A key reason for this has been that Japanese companies never truly took advantage of global value chains, preferring to keep most of their front-end fabrication in Japan. In contrast, the U.S. semiconductor industry leveraged global value chains, allowing enterprises in other nations, and especially in Taiwan, to specialize in manufacturing, assembly, test, and packaging, while U.S.-headquartered companies largely specialized in the higher-value-added activities of branding, R&D, chip design, and understanding how to leverage the chip sets into a wide range of high-value-added goods from smartphones to autonomous vehicles to Internet of Things applications. This empowered a key difference between the U.S. and Japanese semiconductor sectors over the past three decades, with the American firms being able to keep production costs low, making them more cost competitive, in part through leveraging specialized value-chain partners.[50] This does not mean U.S. policy should not seek to incentivize greater domestic production (and R&D) in the industry here; but rather that global supply chains have been a key to U.S. leadership in this sector.

The ability to effectively leverage international supply chains can in part explain national leadership in semiconductor industries.

Another advantage of the dispersion of global semiconductor supply chains and the multiplicity of suppliers has been resiliency and redundancy in overcoming supply chain disruptions. This has been proven through a number of situations, including the 2011 Tōhoku earthquake and tsunami in Japan, major Indonesian earthquakes and tsunamis in both 2004 and 2018, and even the recent coronavirus crisis.

While some countries (or policymakers therein) have called for fully nationalized, closed-loop semiconductor supply chains, a globalized supply chain offers significant benefits from a resiliency perspective, in addition to an economic cost perspective.

COUNTRIES’ SEMICONDUCTOR COMPETITIVENESS STRATEGIES

A number of countries have articulated comprehensive national competitiveness strategies in the semiconductor sector. This section highlights several of these countries’ strategies.

China

In June 2014, the Chinese government published “Guidelines to Promote [the] National Integrated Circuit Industry” (the China “National IC Plan”) which called for $150 billion in investment from central, provincial, and municipal governments to facilitate development of a fully closed-loop semiconductor ecosystem in China, with China ideally to become self-sufficient in every facet of semiconductor manufacturing—from R&D and design to fabrication and ATP.[51] As part of this plan, China wants 70 percent of the semiconductor chips used by companies operating in China to be domestically produced by the year 2025.[52] As of 2017, the Semiconductor Industry Association (SIA) estimated that China had raised $80 billion of the $150 billion goal.[53] In October 2019, China supplemented these investments by announcing a new national semiconductor fund of 204.2 billion yuan ($28.9 billion) financed by central- and local-government-supported enterprises including the State Tobacco Monopoly Administration (STMA) and the China Development Bank Corp.[54] And, early in 2020, China’s Ministry of Industry and Information Technology announced a “New Infrastructure” campaign seeking to make at least $1.4 trillion in investments over the next five years in AI, data centers, mobile communications, and other projects.[55] This matters to China’s semiconductor sector because the investments made through the fund would ideally go to digital technologies using Chinese-manufactured semiconductors.

As of 2019, China accounted for 17 percent of global semiconductor chip manufacturing, with that share expected to increase to 28 percent by 2030, in part thanks to the Chinese government currently funding the construction of more than 60 new semiconductor fabs.[56] Although China is unlikely to meet its goal of 70 percent self-sufficiency by 2035, analysts expect it will be able to meet 25 to 40 percent of its domestic demand with locally designed semiconductors by then.[57] China views the semiconductor sector as the lynchpin of its digital development and even broadest-scale economic growth plans, and has proven itself willing to utilize every tool at its disposal in its efforts to develop a world-class semiconductor industry.

European Union

In May 2013, the European Commission announced an EU-wide strategy for micro- and nano-electronic components and systems. An implementation plan for the strategy called for European companies and governments “to invest at least €35 billion ($41.4 billion) in the sector by 2025.” In support of the strategy, two new instruments were launched at the European level in 2014: the Electronic Components and Systems for European Leadership (ECSEL) Joint Undertaking, which funds research, development, and innovation projects in electronic components and systems, and the IPCEI (Important Project of Common European Interest) instrument. To date, €2.6 billion ($3.1 billion) has been invested in 51 ECSEL projects involving more than 1,600 research, development, and end-user organizations in collaborative research and innovation.

Despite this, some commentators, including Dr. Friedrich Dornbusch, have written that over the past half-decade there has been “insufficient alignment of the European member states on a common semiconductor strategy.”[58] To address that, in 2018, EU Commissioner for Digital

Economy and Society Mariya Gabriel commissioned a study on “Boosting Electronics Value Chains in Europe.”[59] The resulting strategy document outlined an eight-step action plan to revitalize European competitiveness in electronics and microelectronics: 1) Extend Europe’s partnership success model; 2) Continue investment toward a strong microelectronics manufacturing industry; 3) Create a strategic sovereignty program; 4) Create a smooth innovation path from IP to products; 5) Pursue strategic design initiatives; 6) Create design tools for electronic value chains; 7) Create a task force for electronic education and skills; and 8) Create a pan-European research infrastructure for advanced-computing technologies.[60]

Each segment of the semiconductor value chain has, on average, 25 countries involved in the direct supply chain and 23 countries involved in support functions.

Perhaps most significantly, at year-end 2018, the European Commission approved the “Important Project of Common European Interest (IPCEI) on Microelectronics,” which will facilitate transnational cooperation projects in microelectronics across four European nations: France, Germany, Italy, and the United Kingdom. The program permits the use of state aid for microelectronics industrial competitiveness. Twenty-nine European companies are directly involved in the Microelectronics ICPEI, which includes over 40 sub-projects divided into 5 technology fields: energy efficient chips, power semiconductors, sensors, advanced optical equipment, and compound materials.[61] Funding for the IPCEI has come from the participating countries themselves, not the European Union.

Of note as well in the strategy is “a call for a specific 'sovereignty' programme to be put in place to support and develop essential assets for critical electronic components, leading to guaranteed access to and control over secure and trusted components for strategic European infrastructure and systems.” This would target “essential technologies, components and product lines for aerospace, defense, security, and critical infrastructures.”[62] While there’s understandably a need for trusted semiconductors in mission-critical national security systems and defense platforms, Europe should still work wherever possible with vendors from like-minded nations, and more broadly eschew the notion of “digital sovereignty,” which unfortunately has become increasingly prevalent in Europe.

Germany

In 2019, Germany’s Federal Ministry for Economic Affairs and Energy contributed €275 million ($312 million) to the European microelectronics programme to boost the competitiveness and innovation capacity of Europe’s semiconductor industry.[63] From 2019 to 2021, Germany is committing a total of €1 billion to the effort. In June 2020, Germany’s Federal Ministry of Education and Research (BMBF) unveiled 2 new funding programs with a combined value of €45 million ($50 million) with the aim of developing "trusted" electronics. Through the so-called “Zuse” program, Germany’s BMBF plans to support 3 processor development projects with €25 million (almost $30 million). In addition, starting in 2021, a further €20 million (almost $25 million) will be devoted for the development of a “trusted ecosystem” into which domestic hardware and software components are to be integrated.[64] Germany’s BMBF is still evaluating to what extent these programs will be enacted within Germany itself, or as part of broader European microelectronics initiatives.

Japan

Despite its decorated history of leadership in semiconductor innovation, and enduring technical ability and talent base, Japan's semiconductor industry has languished in recent years. Part of this, as noted previously, is attributable to Japan's slow embrace of the fabless-foundry model. Another facet was the 1986 U.S.-Japan Semiconductor Agreement, in which Japan agreed to limit its exports of semiconductors, particularly DRAM chips, to America, and increase the sales of American-made memory chips in Japan to 10 percent of their market.[65] Another challenge for Japan's semiconductor and broader technology industry, for much of the 1990s and early 2000s, was that Japan's ICT sector tended to isolate itself from global markets, suffering from a "Galapagos Island syndrome" of market and technology isolation that ultimately left many of the country's firms uncompetitive in the global economy.[66]

In fact, whereas Japanese companies commanded 35 percent of the global semiconductor industry in 1982, the country's share of global semiconductor industry value added has fallen to less than 10 percent, and Japan now only has 1 company ranking in the top 15 of global semiconductor sales.[67] Japan's Ministry of Economy, Trade, and Industry acknowledged Japan's industrial shortcomings (including in semiconductors) in a 2016 report entitled "Initiatives for Promoting Innovation," which attributed today's challenges to a delay in response to environmental changes, closed R&D investments, short-termism of private companies, low mobility of personnel and funds, and isolation from global networks.[68] Attempting to tackle some of these challenges, Japan passed an Industrial Competitiveness Act and has promulgated a Japan Revitalization Strategy, which collectively seek to "revitalize the Japanese economy and enhance the industrial competitiveness of enterprises doing business in Japan."[69] More recently, Japan's Society 5.0 vision articulates the country's vision for future digitalization, which calls for Japan to become a leading manufacturer of semiconductors for "specialized for AI applications."[70]

South Korea

In 2019, South Korea's Ministry of Trade, Industry, and Energy (MTIE) launched a new semiconductor competitiveness strategy that seeks to make the country a leading competitor and invests 1 trillion won ($830 million) over the next 10 years toward developing next-generation semiconductor technologies and training 17,000 high-end professionals.[71] The strategy includes 100 billion won ($83 million) earmarked for the creation of a fabless business fund. The strategy also calls for developing a cooperative platform called "Alliance 2.0" that would involve 25 private and public organizations in areas where there is high demand for system semiconductors, or where South Korean companies can secure competitiveness within a short time frame, focusing on five major strategic areas: automobiles, biotechnology, energy, Internet of Things-based home appliances, machinery, and robots. The plan calls for South Korea to capture 10 percent of the market share in the fabless (i.e., chip design) sector by 2030, in addition to maintaining a leading position in manufacturing semiconductor memory chips. Further, in July 2020, MTIE announced that South Korea will invest over 5 trillion won ($4.1 billion) in the materials, parts, and equipment industries to ensure stable supplies for the nation's key exporters. Of that amount, 2 trillion won ($1.6 billion) will be allocated for the nation's 3 most-significant industries in 2021, including semiconductors, biotechnology, and future mobility sectors.[72]

United States

In 2017, the Obama administration's President's Council of Advisors on Science and Technology (PCAST) produced a report on "Ensuring Long-term U.S. Leadership in Semiconductors," which set out a vision for U.S. semiconductor competitiveness predicated upon: 1) a competitive domestic sector supported by basic R&D funding, policies aimed at developing and attracting talent, reforming corporate tax laws, and reforming permitting practices; 2) combatting foreign innovation mercantilism; and 3) a series of moonshots aiming to drive transformative innovation in the sector.[73] While the agenda contained a number of useful recommendations, it lacked any real strategy for encouraging more construction of semiconductor fabs in the United States.

The Trump administration has not articulated a formal strategy for the sector, but picked up on several elements from the Obama strategy, including taking steps to contest China's non-market-based strategies to grow its semiconductor sector. The Trump administration placed, among others, Chinese DRAM chip manufacturer Fujian Jinhua Integrated Circuit Company on the entity list (thus restricting the firm's ability to import key sensitive technologies) for trying to steal U.S. IP, imposed export control restrictions on Huawei, and pressured Dutch EUV lithography manufacturer ASML not to sell critical semiconductor production to China's SMIC.[74] The Trump administration has also encouraged U.S. and foreign firms to increase their semiconductor manufacturing activity in the United States, leading, in part, in 2020 to TSMC committing to open a new U.S. fab in Arizona.[75]

The administration has also partnered with key members of Congress to propose two new pieces of legislation (since combined) designed to bolster U.S. semiconductor competitiveness. First, Senators John Cornyn (R-TX) and Mark Warner (D-VA) introduced the bipartisan Creating Helpful Incentives to Produce Semiconductors (CHIPS) for America Act, which was followed by Senators Tom Cotton (R-AR) and Chuck Schumer's (D-NY) introduction of the American Foundries Act (AFA) of 2020.[76] The two pieces of legislation have since been merged, and a consolidated version of the legislation was included in the 2020 National Defense Authorization Act (NDAA), which passed in the House and Senate in July 2020.[77] (Note: The NDAA legislation will now go to conference committee, where further negotiations will occur, including over budgeting, so the figures below reflect budget requests as included in the initial legislative proposal. Except for a $1.2 billion authorization for R&D in the House version of the legislation, the versions of the legislation in the NDAA do not contain specific authorization amounts). The legislation would expand federal investment in semiconductor research and technology development, introduce incentives to locate semiconductor manufacturing facilities in the United States, and provide expanded tax credits for investment in the sector. Among other elements, the legislation would:

- Provide $10 billion (CHIPS Act) to $15 billion (AFA) in matching grants for WTO-consistent state/local incentives to attract semiconductor manufacturing facilities, which would help level the playing field with other nations' incentives;
- Invest $12 billion over five years (CHIPS Act, AFA calls for $5 billion) for semiconductor research at agencies such as the National Science Foundation (NSF), Department of Energy, and the Defense Advanced Research Projects Agency (DARPA);
- Introduce a $750 million multilateral security fund to support development and adoption of secure microelectronics and secure microelectronics supply chains;

- Create a Manufacturing USA Institute for Semiconductor Manufacturing as well as a National Semiconductor Technology Center to research and prototype advanced semiconductors;
- Introduce a refundable 40 percent investment tax credit for semiconductor equipment and facilities expenditures; and
- Launch initiatives to support the development and adoption of secure microelectronics and secure microelectronics supply chains.

The pressing need for the CHIPS/American Foundries Act was brought home in stark relief with Intel's July 2020 announcement that it had fallen at least 1 year behind schedule in developing its next major advance in chip-manufacturing technology, that is, in moving from 10- nm to 7- nm technology.[78] (Intel CEO Bob Swan even noted that the company might have to use a competitor's manufacturing facilities if it is unable to resolve the delay quickly.) In a way, Intel is a victim of its own success in the sense that it was Intel co-founder Gordon Moore's famous Moore's Law which conditioned onlookers to assume the law would continue indefinitely as a simple matter of course. As such, what this fundamentally illustrates is not that Intel suddenly got poor at engineering, but rather the extreme difficulty and complexity of innovating in this industry, which requires significant investment to continue to advance. That's why public-private partnerships, especially in R&D, have been so important to the evolution of the industry and continued U.S. competitiveness therein. As the Information Technology and Innovation Foundation (ITIF) has noted in other reports, if the United States is to have a healthy and robust economy, it must be competitive in manufacturing, especially in advanced-technology industries such as semiconductors, meaning that initiatives such as those contemplated in the CHIPS/American Foundries Act aren't misguided industrial strategies or corporate handouts, but rather appropriate, WTO-consistent efforts to support the competitiveness and innovation capacity of the sector broadly.

Beyond this, there exist a number of semiconductor R&D programs being run out of various government agencies (as described subsequently). In short, the actions of the past two administrations, combined with heightened attention from Congress, suggests the United States is finally becoming serious about bolstering its semiconductor competitiveness, especially in light of peer nations' attempts to do the same. Notwithstanding this, to date, America's semiconductor policies and programs have been disjointed and inadequately funded. The nation would benefit from a regularly updated, comprehensive national semiconductor competitiveness strategy.

COLLABORATING TO COLLECTIVELY ENHANCE SEMICONDUCTOR COMPETITIVENESS

It's certainly appropriate, and indeed laudable, for countries (or supra-national regions such as the European Union) to articulate comprehensive strategies to advance the competitiveness of their nations' semiconductor industries. Despite the contentions made be some that, "The notion that nations compete is incorrect … countries are not to any important degree in competition with each other," the reality is that nations do compete with one another to achieve greater levels of economic growth.[79] As ITIF wrote in *Innovation Economics: The Race for Global Advantage*, this competition increasingly centers around nations' efforts to incubate, scale, and grow (or attract) industries and enterprises competing in the highest value-added sectors of economic activity, such as advanced industrial manufacturing, aerospace, biotechnology, renewable energy, and semiconductors (and other digital and ICT sectors).[80] While it's appropriate for nations to compete intensely for leadership in advanced-technology industries, the policies they implement to do so should always be positive sum in nature, investing in the global stock of knowledge and know-how, through policies such as investing in R&D, education, and infrastructure. When nations elect to compete by implementing certain policies such as restricting market access, tech transfer as a condition of market access, subsidizing industries, or influencing technology standards, they harm other nations and enterprises therefrom and damage the global economy.[81]

Yet, while nations compete, they also trade with each other for mutual gain. Moreover, there are opportunities for scientific, technical, and trade collaboration that can advance a base of knowledge upon which private-sector competition can unfold. A classic example is the Human Genome Project, a multi-billion-dollar global effort that unlocked the field of genomics and in turn unleashed a new era of biopharmaceutical innovation. Similarly, in semiconductors, especially given the extreme expense and complexity of innovating in the sector, there exist opportunities for collaboration that can collectively drive like-minded nations' own semiconductor industries forward in a pro-competitive way. This becomes especially important when some nations elect to compete in the sector substantially through mercantilist and distortive economic trade practices that undermine market-based competitors in the industry, and as national security concerns increase.

Given the extreme expense and complexity of innovating in the sector, there exist opportunities for collaboration that can collectively drive like-minded nations' own semiconductor industries forward in a pro-competitive way.

Like-minded, allied nations need to find more ways to work together on semiconductor policy and programs, recognizing that "open societies are stronger when they act in unison."[82] The United States should lead such collaboration, for, as one report presciently notes, "Unless the United States builds this community—an 'alliance innovation base'—it will steadily lose ground in the contest … to ascend the commanding technological heights of the 21st century.… The only way for the United States to tip the scale back in its favor is to deepen innovation linkages with its allies."[83]

The opportunity is rich in semiconductors, wherein successful innovation depends upon the work of a complex tapestry of scientists, researchers, and engineers working across a multitude of international companies, universities, government agencies and research institutions, and public-private research consortia. Indeed, the semiconductor industry owes its foundation to, and indeed has been tremendously advanced over a course of decades by, breakthroughs in basic scientific research in fields such as particle physics, materials science, and nanoengineering that benefitted from tremendous levels of cross-national research and international scientific publications. If nations work together to co-fund R&D, build industry technology roadmaps, develop voluntary technology standards, and craft liberalized trade rules, they can collectively build a semiconductor ecosystem positioned to successfully compete against those of nations that pursue an autarkic path.

Unfortunately, the history of information and communications technology shows that nations can choose to isolate themselves. For much of the 1990s and early 2000s, Japan's ICT sector isolated itself, suffering from a Galapagos Island syndrome of market and technology isolation that ultimately left many of the country's firms uncompetitive in the global economy.[84] Today, it's concerning that the European Union has elected to frame so much of its new industrial strategy around the goal of gaining "digital sovereignty." These and other allied nations need to think bigger and broader and focus on "allied nation digital sovereignty," or at least allied national semiconductor competitiveness. As such, the United States should work with European peers to reframe Europe's objective to be about achieving advanced-industry leadership in a broad range of sectors and technologies, not just in the digital sphere, and to do so while maintaining a commitment to free trade and global innovation.[85] And it always does well for the United States to remember these lessons itself.

The following sections articulate how like-minded nations can collaborate across four areas: semiconductor technology development, technology protection, ecosystem development, and trade liberalization.

COORDINATED TECHNOLOGY DEVELOPMENT

As noted, the expense and scale required to successfully innovate in the semiconductor sector make it difficult for any one nation, let alone any one enterprise, to go it alone. There are several ways like-minded nations and enterprises therein can collaborate to collectively raise the competitiveness of their respective semiconductor sectors.

Establish Manufacturing USA Institutes(s) Supporting Semiconductor Manufacturing, Including in R&D, Manufacturing, and ATP. America's Manufacturing USA network constitutes a public-private partnership consisting of 14 Institutes of Manufacturing Innovation dedicated to developing advanced manufacturing product and process technologies.[86] PowerAmerica, the second Institute established, focuses on accelerating adoption of wideband advanced semiconductor components made with silicon carbide and gallium nitride.[87] In 2018, Manufacturing USA leveraged $183 million in federal funds to attract $304 million in private-sector and state-government investment.[88] The CHIPS Act calls for creating an Advanced Packaging National Manufacturing Institute that would "establish U.S. leadership in advanced microelectronic packaging and … support [a] domestic advanced microelectronic packaging ecosystem."[89] To be sure, there could be several possible facets of the semiconductor fabrication process meriting their own Manufacturing USA Institute, including ones focused on semiconductor design, advanced semiconductor fabrication processes, semiconductor tooling, or advanced microelectronic packaging. ITIF has called for Congress to give the Secretary of the Department of Commerce the ability to adopt an "affiliates model" that would permit the agency to designate as members of Manufacturing USA organizations that are substantially similar to existing institutes as a way to rapidly expand the Manufacturing USA network, including as a way to establish additional semiconductor-focused institutes.[90]

The Manufacturing USA program provides a proven model that should be central to the United States' efforts to build a stronger and globally connected and competitive semiconductor sector. It has proven a useful vehicle for collaboration with international firms on advanced-technology innovation. For instance, PowerAmerica's members include ABB, BAE Systems, Infineon, and Toshiba, while MxD, which focuses on digital manufacturing, counts as members international firms including Rolls Royce and Siemens.[91] As the U.S. Government Accountability Office explained, "Under some institutes' agreements, foreign members are allowed if the sponsoring agency approves such members and certain conditions are met, such as having a significant manufacturing footprint in the United States."[92] But if the United States looks to stand up more semiconductor-focused Manufacturing USA Institutes, it's critical that foreign semiconductor enterprises (including ones from the manufacturing and fabless sectors) not only be allowed, but encouraged, to join them, given the global nature of the semiconductor sector. As long as these firms have a manufacturing, production, or R&D process in the United States, they can contribute to the overarching goal of growing the U.S. semiconductor sector. At the same time, such partnerships should be based on reciprocity as a touchstone principal: Foreign nations should allow U.S. semiconductor enterprises to participate in their similar initiatives on equivalent terms. Foreign nations that have similar pre-competitive research institutes show allow U.S.-headquartered firms to participate on reciprocal terms.

Expand International Cooperation in Semiconductor-Sector Public-Private Partnerships. Collaborative, pre-competitive research and the development of coordinated industry technology roadmaps have long been a hallmark of the semiconductor innovation process, especially given the expense and scale required to successfully innovate in the sector. The archetypal case is SEMATECH, a consortium of 14 U.S.-based companies which convened in 1988 to conduct pre-competitive (though applied) R&D to produce generic semiconductor manufacturing technology with a stated goal of achieving world leadership in manufacture of 0.35 micron devices.[93] The U.S. Department of Defense (DOD), via DARPA, supported SEMATECH with $500 million over a 5-year period, with industry and some states and universities providing additional contributions. SEMATECH's R&D efforts focused on lithography processes (including steppers, photoresists, mask-making, and metrology), working with multilevel metals (etch, planarization, and deposition), and process technologies such as manufacturing systems and process integration.[94] SEMATECH yielded technological breakthroughs in semiconductor design and manufacturing processes that rallied an industry and infrastructure in near collapse, allowing U.S. semiconductor manufacturers to achieve technological parity with Japanese competitors and remain competitive in the decades hence.[95] In 1996, SEMATECH's board voted to eliminate matching funds from the U.S. government, and the organization's focus shifted from the U.S. semiconductor industry to the larger international semiconductor industry. In part due to subsequent consolidation in the semiconductor industry, in 2015, SEMATECH merged with the SUNY Polytechnic Institute and moved beyond semiconductors to oversee research, development, and commercialization in other industries such as green energy, power electronics, and biotechnology.[96]

Successful semiconductor innovation depends upon the work of a complex tapestry of scientists, researchers, and engineers working across a multitude of international companies, universities, government agencies and research institutions, and public-private research consortia.

While SEMATECH has moved on, today the Semiconductor Research Corporation (SRC), a technology research consortium that seeks "to assemble the best university researchers while educating an elite workforce of talented graduate students—in science, engineering, and technology," plays a key role.[97] SRC represents an effective platform for engagement with like-minded nations interested in collaboratively advancing semiconductor technology development, as it already works with many of the world's leading semiconductor firms (both U.S. and foreign). As SRC CEO Ken Hansen explains, "SRC launched in 1982 with a mission to fund university research in the pre-competitive stage to leapfrog the technology disadvantage we felt at the time and to develop a workforce pipeline of well-educated Ph.D. students working on industry-relevant topics."[98] SRC runs the Joint University Microelectronics Program (JUMP), which focuses on high-performance, energy-efficient microelectronics in partnership with DARPA and also the nano-electronic Computing Research (nCORE) program in partnership with NSF and the National Institute of Standards and Technology (NIST).[99] In 2018, SRC initiated an effort to bring together companies, academics and students, government agencies, and other stakeholders to create a "Decadal Plan for Semiconductors" that would chart the R&D needs of the sector over the coming decade as a guide for both academic researchers and students looking to earn advanced degrees in the field.

The Decadal Plan for Semiconductors seeks to transform the future of the global semiconductor industry by: 1) informing and supporting the strategic visions of semiconductor companies and government agencies; 2) guiding a (r)evolution of cooperative academic, industry, and government research programs; and 3) placing a "stake in the ground" to challenge the best and brightest university faculty students.[100] The Decadal Plan seeks to develop effective approaches to deal with looming challenges confronting the semiconductor (and broader ICT industries), including: 1) continuing to achieve exponential decreases in compute energy required to execute computations, lest energy expenditures limit the growth of computational capacity; 2) addressing the analog data deluge (i.e., rapidly processing massive amounts of data); 3) meeting the dramatic increase in global data storage requirements; 4) advancing communication technologies to transmit data rapidly and seamlessly; and 5) addressing emerging security challenges, from hardware to AI to the cloud.[101]

To be sure, collaborative R&D efforts on close-to-market applied R&D activities, in the semiconductor or any other technology sector, are challenging, even when such collaborations involve only domestic players, let alone international ones. However, at the five-to-ten-year, and even three-to-five-year, timescales, when nations have pulled their semiconductor technologists, they've often identified research opportunities that, while perhaps not appealing for any one country to undertake, can still generate immense significant scientific value in high-risk, high-reward areas of research. Research at those timescales, for instance, could include new approaches to computing architectures, such as in-memory compute, special-purpose compute engines, brain-inspired/neuromorphic computation, and quantum computing. Players from like-minded nations should pull together their chief technology officers (and other technologists), academic researchers, and policymakers to create a roadmap for areas of priority research that no one country wishes to pursue alone (and that does not veer into the commercial space) and identify opportunities to collectively advance the long-term development of their semiconductor industries. **If the United States takes a leading role in this effort, it should consider establishing a "green list" of countries whose stakeholders would be invited into such collaborations.** The $750 million multilateral security fund envisioned by the CHIPS Act to support development and adoption of secure microelectronics and secure microelectronics supply chains would be an excellent first step in this regard, and Congress should be sure to appropriate such funding as it reviews the NDAA this fall.

However, such collaboration will have a limited impact unless the United States and like-minded nations increase funding for these types of collaborative, pre-competitive R&D efforts, and ensure that there is reciprocal opportunity for semiconductor enterprises from like-minded nations to participate in

such consortia. In 2019, the U.S. federal government invested just $1.7 billion in core, semiconductor-specific R&D (along with an additional $4.3 billion in research in semiconductor-related fields). And whereas 40 years ago federal funding for semiconductor R&D was more than double the level of private-sector funding, in 2019, U.S. private sector investment of about $40 billion in semiconductor R&D was 23 times greater than the federal government's level of investment.[102] However, even with regard to the $1.7 billion in annual federal R&D investment in semiconductor-industry R&D, much of this is agency program manager-led, and **America's semiconductor R&D investments could achieve much greater impact if programs and initiatives were more effectively coordinated across the federal government.** Beyond increasing R&D funding, **the impact and commercialization potential of these types of consortia could be increased with more-flexible federal contracting guidelines, such as a relaxation of Federal Acquisition Regulations or the ability to make greater use of other transactional authority vehicles** (as SRC and DARPA have used for over 20 years, but which could be used more broadly).[103]

DOD also operates several important collaborative research initiatives advancing semiconductor innovation. For instance, in 2013, DARPA launched the Semiconductor Technology Advanced Research Network (STARnet), which engaged 8 companies and 46 universities to identify paths around the fundamental physical limits threatening the long-term growth of the microelectronics industry.[104] In 2017, DARPA launched a larger program, the Electronics Resurgence Initiative (ERI), which aims to forge forward-looking collaborations among the commercial electronics community, defense industrial base, university researchers, and DOD to address related challenges.[105] ERI will be a 5-year effort receiving $1.5 billion in federal funding and encompassing over 20 different DARPA programs. ERI's specific areas of R&D focus include: 1) 3D heterogeneous integration; 2) new materials and devices; 3) specialized functions; and 4) design and security. ERI partners must ensure that program benefits differentially accrue to the U.S. commercial and defense base.[106] However, ERI does host annual summits about its various research programs, which present opportunities for international exchange and collaboration.

Collaboration will have a limited impact unless the United States and other like-minded nations increase government funding for collaborative, pre-competitive R&D efforts.

Europe also features several important research consortia focused on semiconductor and microelectronics pre-competitive R&D. Dutch-headquartered Imec seeks "to be the world-leading R&D and innovation hub in nano-electronics and digital technologies."[107] With over 4,000 researchers spread through several European facilities, 5 in the United States, and 4 in Asia, Imec aims to be a leader in applying semiconductor-driven digital innovation to many economic sectors, including automotive, health, transportation, energy, and sustainability. A core focus at Imec is driving microchip miniaturization and advancing application-specific microchip technology. In Grenoble, France, CEA-Leti helps companies performing micro- and nano-technology research bridge the gap between basic research and manufacturing.[108] Thirty-seven companies have been formed out of Leti as spin-offs, resulting in the creation of more than 2,500 jobs.

Collectively, these research consortia and initiatives across the United States, Europe, and Asia play vital roles in driving semiconductor-sector innovation, engaging both domestic and international partners in activities such as pre-competitive R&D, technology roadmapping, integrating key small to medium sized enterprises into industrial supply chains, and workforce training and credentialing. In particular, observers note that the role of common industry technology roadmaps have played a crucial role in establishing a multi-decade industry vision and keeping Moore's Law on-track. However, several observers noted that as the 3 nm threshold arrives, semiconductor innovation is becoming increasingly application-specific—with customized microchips for AI, driverless vehicles, 5G, graphics-intense applications, smart grids, etc.—and so industry-wide technology roadmaps may be less impactful in the future as innovation pathways in the sector bifurcate. **Nevertheless, the United States and governments of like-minded nations should increase R&D investments in these types of consortium-based pre-competitive research programs, and explore opportunities for greater international participation and collaboration.**

Enrolling Allied Partners in Semiconductor Moonshots

Like-minded partners not only need closer collaboration, but specifically targeted cooperation. The 2017 PCAST report on "Ensuring Long-term U.S. Leadership in Semiconductors" called for identifying "carefully selected ambitious challenges or 'moonshots,' as focal points for industry, government, and academic efforts to drive computing and semiconductor innovation forward together."[109] As the report notes:

> Our recommended approach to designing the moonshots is driven by the fact that the future of semiconductors and computing lies in innovating along multiple dimensions: new ways of performing calculations (such as non-von Neumann and approximate computing), utilization of materials other than silicon (such as carbon nanotubes and DNA for computation and storage), and novel approaches to integrating semiconductors into the devices we use (such as embedding into fabrics and the Internet of Things).[110]

Possible semiconductor-sector moonshots PCAST identified include:

- Developing affordable desktop semiconductor fabrication capabilities that could take the place of a billion-dollar fabrication facility and allow the production of small batches of structures;
- Using 3D printing at the nanoscale to connect "hard" electronic materials with "soft" biological materials, which could be the foundation of a zero-day bio-threat detection network; and
- A commercial, gate-based quantum computer to work on large-scale problems.

The first moonshot objective, in particular, around increasing semiconductor R&D efficiency, in both design and manufacturing processes, could be ripe for coordinated co-investment among like-minded nations. For instance, a representative of one semiconductor company noted that today it can take as many as 2,000 people up to 2 years to develop a new-to-the-world semiconductor design, and that industry should endeavor to collectively cut both components by a factor of at least 10.

The PCAST report suggests that semiconductor-sector moonshots should be designed with a 10-year time horizon, focus on reducing design costs, take an applications-driven approach, and compensate for areas of weak industry investment, "Government will also almost certainly need to back these efforts with significant, catalytic funding to overcome the risks associated with radical innovation."[111] The PCAST report also suggests several "best-practice models" that could advance progress toward achieving the moonshots, including the use of incentive prizes, creating an industry-led venture capital consortium, establishing a Manufacturing USA Institute for semiconductor moonshots, and expanding U.S. government-sponsored industry-academic research fellowships in the field.[112] While all these are positive proposals and should be pursued, given the significant investments required to pursue these worthy moonshots, **the U.S. government should invite other allied nations to co-invest in the moonshots, with resulting IP and technical discoveries shared at levels proportionate to mutual investment** (as appropriately adjusted for nations' economic size).

The U.S. government should consider inviting partners from like-minded nations to co-invest in the moonshots, with resulting IP or technical discoveries shared at levels proportionate to mutual investment.

Enrolling Allied Partners in Trusted Foundries

DOD's Trusted Foundry program seeks to assure the integrity and confidentiality of integrated circuits during design and manufacturing while providing the U.S. government with access to leading-edge microelectronics technologies for both trusted and non-sensitive applications.[113] DOD established the Defense Microelectronics Activity (DMEA), which manages a list of trusted foundries, to ensure that all branches of national defense have access to trusted electronic components.[114] Global Foundries, Integra, and On Semiconductor are some of the more commercially oriented companies (apart from primarily defense companies such as General Dynamics and Lockheed Martin) among the 78 currently accredited suppliers.[115] Bolstering the security and integrity of America's trusted base of integrated circuit providers has recently been a key objective for DOD. For instance, DOD's Trusted and Assured Microelectronics initiative, which focuses on securing the manufacturing layer of the value chain used for domestic supply, has the second-largest budget among 90 DOD R&D programs for 2020.[116] In addition to developing technology, the initiative seeks to revise trust and assurance standards, resulting in a competitive advantage for the United States and its partners in delivering secure and reliable microelectronics.[117]

Certainly, ensuring trusted suppliers for the integrated circuits that go into national security-critical satellites, missiles, and weapons platforms requires the highest standard of trusted supply. However, **the United States should explore additional opportunities to enroll peers from allied nations in the trusted foundries program, with allied nations acting reciprocally for their related programs.**[118] For instance, any Five Eyes country (an intelligence alliance currently comprising Australia, Canada, New Zealand, the United Kingdom, and the United States) is eligible to submit firms for accreditation. As one example, in 2011, Australia's Silanna Semiconductor received an Accreditation of Trust (which persists as of June 2020), signaling that the company's facilities have the security procedures, storage locations, computer systems, and personnel clearances to ensure that defense information is handled, stored, and manufactured in a secure fashion.[119]

Taiwan-headquartered TSMC, which is building a $12 billion, 5 nm semiconductor fab in Arizona, has said it's willing to help U.S.-based customers meet the U.S. government's security mandates when it comes to developing semiconductors for military and national security clients.[120] To that end, TSMC has collaborated with Purdue University to open a Center for Secured Microelectronics Ecosystems, which aims to ensure a secure supply of semiconductor chips and related tools all the way from the foundry to the packaged system, with the goal of developing advanced chips that could be detected or traced if security concerns arise.[121] Such new approaches to keep sensitive chip designs secure could allow DOD to use cutting-edge factories not located in the United States, or to permit more foreign-headquartered companies to participate in the program.[122] DOD has initiated a next-generation global procurement program to consider such alternatives as an opportunity to enhance its Trusted Foundry Program.[123] It's encouraging that DOD recognizes the need to exhibit flexibility in terms of its approaches in working with the private sector regarding trusted foundries. It's also important to recognize that there's a difference between the chips needed to support the most-cutting edge military applications versus systems that can be reasonably satisfied through "legacy silicon," that is, systems that can perform just fine using older generations of silicon (i.e., like 14 nm chips), and so there could be different levels of treatment for trusted foundries (i.e., a so-called "trusted foundry-light approach"). Another approach underway is certification of off-the-shelf products, such as efforts of the Defense Innovation Unit at DOD to procure off-the-shelf technology (including electronic products such as M.2 solid-state devices).

Aside from trusted foundries specifically, another way for the United States and like-minded nations to increase government procurement of semiconductors and related products from allied nations would be to **amend their procurement guidelines by adding a fourth key pillar—security—in addition to the traditional standards of price, cost, and quality.** If like-minded nations did so as well, it would mutually incentivize additional allied procurement activity.

COORDINATED SEMICONDUCTOR ECOSYSTEM DEVELOPMENT

Beyond semiconductor technology development specifically, there's also opportunity for like-minded nations to collaborate toward buttressing the broader ecosystem that supports the semiconductor-production ecosystem, such as with regard to standards development and more-secure computing architectures.

Technology Standards

The development of voluntary, transparent, consensus-based, industry-led technology standards has played a catalytic role in fostering the development of interoperable and globalized supply chains for semiconductors and other ICT goods.[124] Developing and applying common global standards instead of differential country- or region-specific standards makes it far more efficient to integrate components across semiconductor and other ICT supply chains.[125] Standards-development processes and systems to ensure conformity to standards—including testing, certification, and laboratory accreditation—are therefore an important part of modern production and trade.[126] While technology standards work best when developed through a collaborative, voluntary, industry-led basis, China has made the development of indigenous technology standards, particularly for ICT products, a core component of its industrial development strategy. However, technology standards unique to any specific nation make it more difficult and costlier for foreign firms to sell their products in international markets, as they need to reconfigure preexisting design and production processes to meet local standards, and even pay royalty fees for products requiring the use of the indigenous standards. This disrupts the global, generally standardized production processes on which many global companies rely in order to compete.

Accordingly, like-minded nations need to continue to advocate for open standards-development processes, both as they relate to semiconductors specifically and to the vast panoply of downstream digital technologies fundamentally predicated on semiconductors, such as 5G, AI, the Internet of Things, and autonomous vehicles, among many others. The starting point for such like-minded nations should be improving their collective surveillance, engagement, and responses to any country advocating for an indigenous standards-setting process, especially when those standards start to act as barriers to trade in high-tech goods.[127]

There's also evidence that some countries are attempting to influence international standards-setting bodies to ensure their technology lies at the heart of (i.e., are considered essential to) the international standard. Accordingly, like-minded nations should support both private-sector engagement in standards development organizations (SDOs) and efforts to host SDO discussions, and highlight the importance of good governance principles (e.g., transparency and openness to industry participation, and consensus-based and fair voting processes).[128] The nature of private-sector-led SDOs makes it hard for any one country to get its way, as the process for approving international standards is based on private-sector representatives (technical experts) who manage a transparent and consensus-based review process. Finally, like-minded nations' parties should be mindful of when other nations attempt to use their own domestic standards as the basis for efforts to influence standards in third countries via government-to-government engagement, foreign investment projects, and commercial contracts.

Collaborating to Develop a More-Secure Computing Infrastructure

As the number of Internet-connected digital devices continues to increase exponentially, and as new computing architectures and approaches such as AI and quantum computing emerge, the importance of assuring secure computing infrastructure only continues to increase. This applies at all levels, including hardware systems including sensors, processors, actuators, and radio; software; networks; and business processes. For instance, some hardware platforms are vulnerable to speculative execution side-channel exploits, as in the Specter and Meltdown hacks.

Thus, like-minded nations, government agencies, and enterprises therein should collaborate to develop a fundamentally more-secure computing infrastructure. As noted, developing a more-secure computing infrastructure is one of the key objectives of the Decadal Plan for Semiconductors. For instance, in November 2019, the UK government provided £36 million ($46 million) to British microprocessor core designer ARM to develop a prototype circuit board using CHERI (capability-system extension to reduced instruction set [RISC] architectures), a DARPA-supported RISC processor.[129] The goal is to develop foundational computing technologies that are more resistant to cyber threats, part of the British government's wider "Digital Security by Design" initiative. It's a nice example of public and private players from multiple nations coming together to build more-secure computing systems. Though it's not directly hardware related, the U.S. Department of Commerce NIST's Cybersecurity Framework—which provides voluntary guidance based on existing standards, guidelines, and practices for organizations to better manage and reduce cybersecurity risk—has been developed in part through collaboration with international partners, and has been made readily available to international stakeholders.[130]

COORDINATED TECHNOLOGY PROTECTION

Just as there's opportunity to collaborate on semiconductor technology development, so are there a number of avenues to coordinate on semiconductor technology protection, such as export controls, investment screening, and better protecting IP such as trade secrets. As the President's Council of Advisors on Science and Technology wrote in its 2017 "Report to the President on Ensuring Long-Term U.S. Leadership in Semiconductors," the United States must "work with allies to strengthen global export controls and inward investment security." The report further notes the imperative of working with allies to "build their administrative capacity to effectively implement appropriate controls and pursue needed investigations."[131]

Achieve Greater Collaboration on Export Controls

Export controls refer to the rules governing the export, re-export, and transfer (in-country) of physical items, software, technology, and sometimes services to various destinations, uses, and users to accomplish certain national security and foreign policy (including human rights) objectives.[132] Most nations have implemented export control regimes governing the ability of enterprises operating in their nations to export sensitive or national security-related technologies to other nations. This section considers U.S. export controls and then multilateral export controls.

U.S. Export Controls

Historically, U.S. export controls have been targeted at technologies that: 1) can be used in military weapon systems; 2) have a proliferation-based component (e.g., weapons of mass destruction (WMD)); or 3) could impact human rights concerns. The system provides for controls to be placed on either end uses or end users (or both). In August 2018, Congress passed the Export Control Reform Act (ECRA), which updated America's Export Administration Regulations (EAR), which are administered by the Department of Commerce's Bureau of Industry and Security (BIS).[133] ECRA contains several positive elements, including codifying into law decades of BIS practices, policies, and regulatory reforms, including export control reforms enacted under the Obama administration; giving permanent statutory authority to EAR to address modern export control issues; and enhancing export control authorities.[134]

There exist a number of avenues for like-minded nations to coordinate on semiconductor technology protection, such as export controls, investment screening, and better protecting IP such as trade secrets.

Section 4817 of ECRA goes further, however, requiring BIS to lead an ongoing interagency effort to identify "emerging" and "foundational" technologies that are "essential to the national security of the United States," and that are not currently identified in one of the multilateral export control regimes, such as the Wassenaar Arrangement.[135] BIS referred to "emerging" technologies as "non-mature" technologies and "foundational" technologies as "mature" technologies. In 2018, BIS identified 14 categories of technology being considered for potential designation as emerging technologies, and solicited stakeholder comments. As of July 2020, BIS had not yet proposed any unilateral controls on the export of "emerging" technologies under ECRA 4817. (In January 2020, BIS did issue a temporary unilateral control over a type of geospatial imagery software specifically designed for AI networks, but this was done under existing export control authorities.) Though couched with a national security justification, ECRA's inclusion of "emerging" and "foundational" technologies arguably represented an effort to extend the U.S. export control regime from a traditional focus on managing the control of defense-related technologies to include commercially related technologies as well. However, part of Congress's intention in extending the U.S. export control regime in such a way was to recognize that China's publicly announced strategy of "military-civil" fusion (MCF) in the development of advanced technologies makes it impossible to determine between how U.S. (or allied) advanced-technology exports to China could be used, thus necessitating an extension of the U.S. export control regime.[136]

However, as ITIF wrote in "How Stringent Export Controls on Emerging Technologies Would Harm the U.S. Economy," several principles should guide U.S. promulgation of further export control policies to ensure they target the underlying issues without adversely affecting innovation, especially with regard to emerging and foundational technologies. First, **export controls must be regularly updated to reflect the global state of play in semiconductor industries, such that controls do not preclude U.S. enterprises' ability to sell goods that are on a technical par with commercially available goods and services from foreign competitors.**[137] For instance, in some cases, overly stringent export control regulations have prevented the sale of noncritical high-performance computing systems to customers in certain nations, a policy decision that has had the unintended consequence of further spurring these nations to pursue their own HPC development programs, in addition to benefitting competitors from other nations. For instance, when Chinese makers of HPC interconnects and high-speed network-interface chips are able to support the development of HPC systems nearing speeds of 100 petaflops, as *Scientific Computing World* has reported, U.S. export controls preventing exports of similar, U.S.-produced components are unlikely to achieve their intended purpose.[138] That's why a thorough understanding of the global state of play with regard to commercially available advanced-technology systems will be vital to developing a U.S. regime of export controls for emerging and foundational technologies. As such, the issue of foreign availability is fundamental to whether BIS should establish a control on an identified emerging technology.[139] **Accordingly, emerging technologies that are ultimately deemed to meet the statutory standards for export controls should be designated as such only in cases of exclusive development and availability within the U.S. market—and the controls should be removed if and when that exclusivity no longer exists.**[140]

Lastly, ITIF's report argues that **the U.S. government must work to coordinate export controls internationally,** for export control regimes are most successful when they are coordinated internationally. As Section 4811(5) of ECRA notes, "Export controls should be coordinated with the multilateral export control regimes. Export controls that are multilateral are most effective, and should be tailored to focus on those core technologies and other items that are capable of being used to pose a serious national security threat to the United States and its allies."[141] Instead of unilaterally identifying a set of emerging technologies as candidates for export controls, the administration should collaborate with like-minded nations to identify a narrow and specific set of technologies that should be subject to export controls, as the following section elaborates upon.

Multilateral Export Controls

The Wassenaar Arrangement, launched in 1996 by 33 co-founding countries (in which 42 countries now participate), was the first global multilateral arrangement on export controls for conventional weapons and sensitive dual-use goods and technologies. Countries participating in the Wassenaar Arrangement maintain export controls for items on agreed-upon lists, which are periodically reviewed to consider technological developments and experiences gained.[142] As the Center for a New American Security notes, the Wassenaar Arrangement has several strengths, including inclusivity, in that it brings together the largest number of American allies; and expansive coverage, in that its broad mandate makes it best positioned to address emerging technologies.[143] But the Wassenaar Arrangement "also has several weaknesses," notably that it requires unanimous consent to include technologies, and its approach to voluntary implementation gives countries considerable latitude over whether and how they limit the exports of items on control lists.[144] Beyond this, the process of trying to get a technology on a Wassenaar control list can take a very long time—so much so that by the time agreement can be reached, the technology has often already substantially evolved. As such, a new approach is needed that represents a middle ground between the United States' recent efforts to introduce unilateral export controls that increasingly seek to accomplish economic or trade policy objectives and the traditional Wassenaar approach, for both semiconductors specifically and advanced technologies more generally. It's also important to recognize that, traditionally, the main purpose of U.S. export control policy has been to prevent the flow to U.S. adversaries of critical technologies that have military applications.[145] There's systemic risk in using national security tools such as export controls as a mechanism to achieve economic and trade policy goals, especially as doing so may engender reciprocal unilateral responses from other nations.

As such, the United States should eschew the application of unilateral export controls and seek to develop a more ambitious and effective plurilateral approach to promulgate export controls among like-minded nations that have indigenous semiconductor production capacity, such as Germany, Japan, South Korea, Taiwan, the Netherlands, and the United Kingdom.[146] These nations should work together to establish a common understanding of both what threats are posed to the global semiconductor industry by enterprises from non-market economies not fundamentally competing on market-based terms, as well as the pace and evolution of semiconductor technology. Then, among themselves, these nations should establish working groups, outside the Wassenaar structure, to develop descriptions of both the semiconductor technologies and related items that warrant controls (beyond what already exists), as well as establish common licensing policies. However, to accomplish this, several peer nations—including Japan, South Korea, Taiwan, the Netherlands, and the United Kingdom—would have to adjust their domestic laws, which were both designed around the 1990s structure of regime-based controls and don't have the authority for unilateral or plurilateral controls or end-use/end-user controls. In other words, to develop a semiconductor export controls regime in this way would require very close collaboration among allied countries, in terms of capacity building, information sharing, intelligence sharing, and developing a common understanding of what threats exist and to what extent they should be addressed through the use of export controls. Allied nations could develop such a plurilateral regime for semiconductors specifically, or for a broader set of advanced technologies (e.g., AI, 5G, quantum, etc.) along with semiconductors.

As noted, to accomplish this would require allied nations to significantly modernize their export control regimes as well. For instance, as Noah Barkin of the Mercator Institute for China Studies (MERICS) notes, "Despite a years-old legislative push to reform the EU's dual-use regulations, the bloc still has a weak mandate on export controls and limited scope to ramp up its scrutiny of emerging technologies."[147] Barkin argues member states should consider giving the European Commission a formal mandate to explore risks related to emerging technologies, as they did with regard to investment screening, and likewise increase availability of resources and subject matter experts. Certainly, Europe will need to get better aligned around its own vision of exports controls on sensitive technologies if a broader community of like-minded nations is to do so.

To assist other nations in modernizing their export control regimes, **Congress should expand the remit and funding for the EXBS Program at the U.S. Department of State.** The EXBS program works with partner governments to identify regulatory and institutional gaps, and provide technical and capacity-building assistance.[148] While the EXBS program has traditionally been more focused on export controls around WMDs and national security-related technologies, its remit could be expanded to assist allied nations in further developing their capacity to evaluate export controls on advanced technologies.

The United States should seek to develop a more ambitious and effective plurilateral approach to promulgate export controls among like-minded nations that have indigenous semiconductor production capacity.

Finally, like-minded nations should recognize that placing export controls on one another's own readily commercially available items only works to collectively undermine their own semiconductor industries. Over the summer of 2019, a long-running historical dispute between Japan and South Korea, dating back to World War II, boiled over into Japan removing South Korea from its "white list" of countries accorded preferential treatment for export licensing. While more than 1,100 products were potentially exposed to enhanced Japanese regulatory scrutiny, South Korean concern focused on three key inputs—hydrogen fluoride, fluorinated polyimide, and photoresists—for which South Korean semiconductor firms were particularly dependent on Japanese suppliers.

While it appears tensions have simmered and that Japan is approving export requests for the chemicals at question in a timely manner, the dust-up had the potential to undermine confidence in international semiconductor supply chains, and inflicted damage on each disputant's own semiconductor industry. As a U.S. International Trade Commission report on the dispute, "The South Korea-Japan Trade Dispute in Context: Semiconductor Manufacturing, Chemicals, and Concentrated Supply Chains," explained, "Japan's actions create incentives for Korean chipmakers to significantly lessen their sourcing from Japanese suppliers, not only in specialized chemicals, but throughout the entire semiconductor supply chain."[149] And, indeed, this came to pass, both as South Korean semiconductor manufacturers began to explore alternative suppliers, and with the country's aforementioned $4 billion effort to invest in parts and supply industries key "to ensure stable supplies for the nation's key exports." With regard to China, the report concludes that the dispute would provide additional incentives to China's already stated goals of self-sufficiency in their domestic semiconductor production.[150]

The incident highlights the need for greater alignment among like-minded nations on semiconductor-related export controls.

Achieve Greater Alignment of Investment Screening Procedures

In addition to ECRA, in August 2018, Congress updated America's foreign investment screening practices by passing the Foreign Investment Risk Review Modernization Act (FIRRMA), updating the remit of the Committee on Foreign Investment in the United States (CFIUS), which screens foreign investment in the U.S. economy. Historically, CFIUS had been limited to reviewing transactions in which a foreign entity or person acquires "control" of a U.S. business. FIRRMA gives CFIUS authority to review foreign investments and other transactions that do not result in foreign control of a U.S. business.[151] Specifically, FIRRMA expands CFIUS's jurisdiction to include certain non-controlling investments in critical technology (including emerging technologies), critical infrastructure companies, and companies with access to sensitive personal identifier information.[152] CFIUS may now review non-controlling "covered investments" by either type of business or type of investment. Type of business includes reviews of investments in companies that own, operate, manufacture, supply, or service critical infrastructure; produce, design, test, manufacture, fabricate, or develop critical technologies; maintain or collect sensitive personal data of U.S. citizens; or that impact "TID U.S. Businesses"—those that operate or manage critical technologies, critical infrastructure, or sensitive personal data. Type of investment includes reviews of investments that provide the foreign entity with access to material nonpublic technical information; membership or observer rights on a board of directors; or any involvement other than through voting of shares in substantive decision-making of the U.S. business regarding the sensitive personal data of U.S. citizens, critical technologies, or critical infrastructure.[153] Critical technologies now include any technology deemed by BIS to constitute an emerging or foundational technology, in addition to defense technologies enumerated on the United States Munitions List, items on the Commerce Control List beyond anti-terrorism, and nuclear technologies. In short, FIRRMA significantly updates America's foreign investment screening procedures to take account of the modern reality of state-directed capitalism characterized by the heavy embrace of innovation mercantilist practices.

The United States should work with like-minded nations to align foreign investment screening practices and to exchange information when it appears other nations are trying to use unfair practices in making foreign investments, such as heavily state-subsidized SOEs attempting to purchase foreign enterprises in advanced-technology industries. For instance, since 2014, Chinese businesses have made at least $56.8 billion in technology-related investments abroad, of which $36.7 billion (65 percent) was invested outside the United States.[154] The largest allied destinations of Chinese tech-related foreign direct investment (FDI) outside the United States have been the United Kingdom, the Netherlands, Germany, France, and Singapore.[155] In fact, FIRRMA instructs CFIUS to "establish a formal process to share information with foreign allied governments and coordinate and cooperate on investment security issues," with the understanding that countries adopting comprehensive foreign investment review processes may remain on CFIUS's list of "excepted foreign states."[156] Australia, Canada, and the United Kingdom are the countries currently on CFIUS's white list, which exempts foreign investors from filing requirements for their non-controlling investments in TID U.S. businesses.[157]

In part spurred by the United States, like-minded nations have in recent years modernized their foreign investment screening practices. In April 2019, the European Union's new framework for the screening of FDI went into force (due to be fully applied in November 2020). It will provide a better instrument to detect and raise awareness of foreign investment in critical assets, technologies, and infrastructure in the EU.[158] The central feature of the EU framework is that it sets minimum requirements for national screening mechanisms and aims to enhance cooperation and information sharing between the commission and member states on specific foreign investments likely to affect security and public order in member states and in the whole EU. However, it neither harmonizes investment screening mechanisms that are currently in place in member states, nor replaces them with an EU-level mechanism.[159] Under this broader EU effort, France, Germany, Hungary, Italy, Latvia, Lithuania, and the United Kingdom have all strengthened or are in the process of strengthening their investment screening regimes, while Belgium, the Netherlands, the Czech Republic, Greece, Slovakia, and Sweden are considering setting up or strengthening investment review mechanisms.[160] Japan has likewise made several amendments to its investment screening framework—the Foreign Exchange and Foreign Trade Act—in recent years, including in August 2019 adding certain ICT-related businesses to its list of businesses subject to special rules limiting FDI.[161]

FIRRMA significantly updates America's foreign investment screening procedures to take account of the modern reality of state-directed capitalism characterized by the heavy embrace of innovation mercantilist practices.

The United States should continue to work with like-minded nations to coordinate investment screening procedures and consider expanding its list of "excepted foreign states" to include countries such as France, Germany, the Netherlands, Italy, Japan, and South Korea (among others). As a recent Brookings Institution report concurs, "The United Kingdom, Germany, Netherlands, France, Italy, and Japan are optimal partners for the United States to prevent the transfer of sensitive technical information through investments," adding that the United States should work to bring in Austria, Finland, and New Zealand as well. As that report concludes, "Allies are vital if the United States is to establish comprehensive, data-driven screening procedures based on the risk of technology transfer."[162]

Expand the Multilateral Action on Sensitive Technologies Process

In 2019, the U.S. government stood up the MAST process, wherein a group of 15 advanced industrial nations (many European) started to come together to share information and best practices on technology-transfer threats, and work together to develop more-effective collective responses.[163] Countries participating in the MAST process are working together on the following four issue areas: export controls; investment screening; visa screening for proliferation concerns; and mitigating risks associated with international scientific and technical collaboration.[164] Following the initial 2019 MAST conference, U.S. officials met with a similar group of like-minded countries on the margins of the annual Wassenaar meeting in Vienna in early December 2019 to discuss with allies an approach that would focus, in three-month intervals, on "sprint groups" that would examine possibly imposing export controls on priority technologies.[165] **At the 2020 MAST conference, scheduled for September 2020, the United States should consider introducing a plurilateral approach to advanced-technology export controls, as described in the previous section.**

Collaborate to Comprehensively Catalog and Combat Foreign Technology and IP Theft

IP is the lifeblood of the global semiconductor industry.[166] Some nations, and enterprises therein, have elected to compete in advanced-technology industries, including semiconductors, through the theft of foreign technology and IP. For instance, in November 2018, the U.S. Department of Justice charged China's Fujian Jinhua Integrated Circuit Co. with working to steal trade secrets from U.S. chipmaker Micron Technologies.[167] The incident spurred the Justice Department to launch a new initiative to combat foreign economic espionage and trade secret theft. That effort yielded results when, in June 2020, the U.S. Department of Justice found Chinese national Hao Zhang guilty of economic espionage and theft of trade secrets from both Avago, a California-based developer of semiconductor design and processing for optoelectronics components and subsystems, and Skyworks, a Massachusetts-based innovator of high-performance analog semiconductors.[168] Taiwanese-based semiconductor manufacturers TSMC and Nanya Technology Corporation have both experienced attempted or effected thefts of trade secrets, including a 2016 incident in which TSMC engineer Hsu Chih-Pen stole TSMC trade secrets he intended to sell to Chinese state-owned Shanghai Huali Microelectronics Corp.[169]

Like-minded nations should take several steps to deal with foreign theft of semiconductor-related technology and IP. **First, like-minded nations should develop a comprehensive list of enterprises and individuals who have attempted or effected IP theft, and develop mechanisms to restrict such firms and individuals from competing in like-minded nations' markets. Second, like-minded nations should enhance information-sharing efforts to combat foreign economic espionage and IP/technology/trade secret theft.** Here, like-minded nations could work to expand the Five Eyes partnership.[170] The alliance provides mutual access between members to intelligence activities, including cybersecurity, and promotes greater levels of military interoperability. There has been discussion about possibly bringing Germany and Japan into the framework.[171] To be sure, there is a significant defense component to the Five Eyes Alliance, so another, potentially broader, approach would be for the **United States to lead like-minded nations in developing a broader Five Eyes-like alliance specifically focused on combatting state-sponsored economic espionage in advanced-technology industries.**

Such an initiative could also be useful in combatting the proliferation of counterfeit semiconductors and other electronic goods. The market for counterfeit semiconductors reached $75 billion in 2019, accounting for just under half of the estimated $169 billion in counterfeit parts circulating through global electronics supply chains.[172] Counterfeit semiconductors or other electronics introduce potentially serious economic, national security, and even safety concerns. The Obama administration developed a "National Strategy for Global Supply Chain Security," and peer nations have developed similar supply chain security strategies; a Five Eyes-like alliance could also work to coordinate best practices in better achieving supply chain security and combatting counterfeiting.[173]

Finally, the United States should continue to work with like-minded nations to strengthen their trade secret protection regimes. This has contributed to both the European Union and Taiwan taking recent steps toward strengthening their trade secret regimes.[174] Further, the United States has supported efforts by OECD and the Asia-Pacific Economic Community (APEC) to launch efforts to increase understanding of the benefits trade secrets can provide, and how to develop laws supporting trade secret rights. For instance, in November 2016, APEC endorsed a set of "Best Practices in Trade Secret Protection and Enforcement Against Misappropriation," which includes best practices such as: 1) broad standing for claims for the protection of trade secrets and enforcement against trade secret theft; 2) civil and criminal liability, as well as remedies and penalties, for trade secret theft; and 3) robust procedural measures in enforcement proceedings.[175] Finally, as noted subsequently, **the United States and other like-minded nations should continue to include robust trade secret protections, and penalties for willful large-scale commercial trade secret theft, in trade agreement they pursue.**

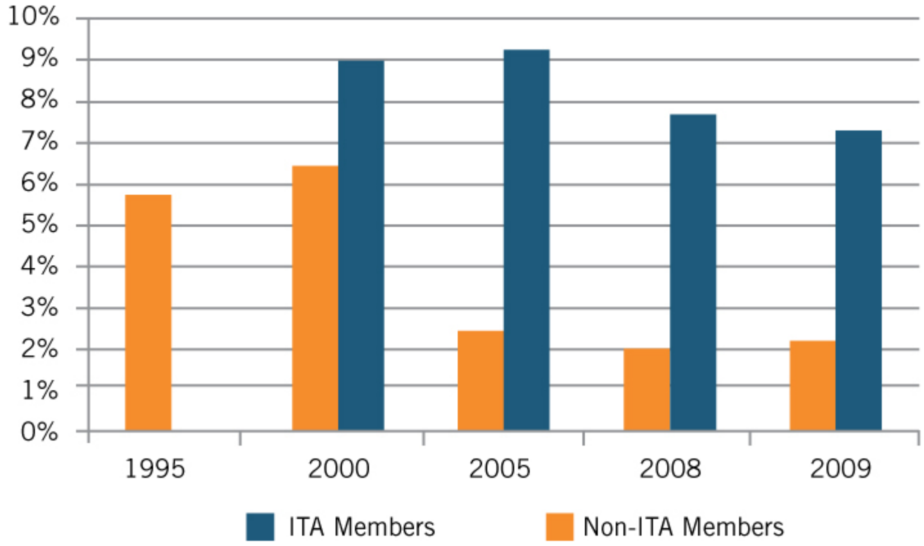
ADVANCE SUPPORTIVE TRADE RULES, REGIMES, AND PRACTICES

Like-minded nations have an opportunity to collaborate more strongly in developing trade regimes, rules, and practices that can better facilitate the smooth operation of semiconductor value chains across open global markets. The following presents several policy proposals.

Elevate the imprimatur and stature of the World Semiconductor Council. The WSC is an international forum bringing together the semiconductor industry associations of China, Europe, Japan, South Korea, Taiwan, and the United States to promote international cooperation in the semiconductor sector and facilitate its global growth.[176] WSC traces its heritage as an outcome of the U.S.-Japan Agreement on semiconductors in the mid-1980s, but counts its official start as 1996, when the semiconductor industry associations from Europe, South Korea, and Taiwan joined the Japanese and U.S. ones (China's joined in 2006). Semiconductors represent perhaps the only advanced-technology industry in the world meeting annually at the C-level with senior government officials from participating nations, through the annual Government and Authorities Meeting on Semiconductors (GAMS). The GAMS meeting seeks to establish shared "rules of the road" to achieve a level playing field and equitable competition in the industry, such as through clarifying nations' policies on subsidies and state aid, or exchanging best practices for regional semiconductor development programs. WSC has also been instrumental in fostering the development of open global markets for semiconductors, with tariff elimination being one of the foundational conditions of WSC eligibility, and the community being key drivers for the advent and expansion of the ITA. WSC and GAMS have been effective initiatives, but there's an opportunity to further raise the global profile of the effort, including by ensuring CEO-level participation from member companies and prevailing upon like-minded nations to bring the most-senior officials possible in their governments to participate in the meetings.

Expand the Information Technology Agreement. The United States and like-minded nations should continue to advocate for market-based economies to join the ITA in full. Introduced in 1996, the ITA represents one of the most successful trade agreements the WTO has ever forged.[177] The 82 members of the original ITA agreement represent countries accounting for 97 percent of world trade in ICT products.[178] By eliminating tariffs on hundreds of ICT goods on a most-favored nation basis, the ITA enables zero-in, zero-out movement of inputs and components essential to the smooth functioning of semiconductor manufacturing supply chains. This matters, because countries maintaining high tariffs on ICT parts and products only make themselves unattractive to multinational enterprises wishing to seamlessly integrate into global supply chains. That explains why the OECD has found that countries not participating in the ITA have seen their participation in global ICT value chains decline by more than 60 percent from 1995 (two years before the ITA went into effect) to 2009.[179] (See figure 12.)

Figure 12: ITA membership and participation in ICT GVCs (participation index in % of gross exports)[180]



*ITA came into effect in 1996

Further, by eliminating tariffs on imports of final covered ICT goods, the ITA bolsters their consumption within economies (in part because ICTs are highly price elastic, meaning reduced prices of goods can perceptibly increase their consumption) and the greater stock of such innovation- and productivity-enhancing ICT goods within nations can bolster their long-term economic growth.[181] In December 2015, over 50 nations implemented an expansion of the ITA that brought 201 new products—many of which had been invented since the original ITA came into force in 1996—under the agreement's coverage.[182] ITIF has found that joining the ITA can engender significant economic growth for developing nations. For instance, over a 10-year period, joining the ITA would bolster Argentina's economic growth by an estimated 1.52 percent; Pakistan's by 1.30 percent; Kenya's by 1.29 percent; and Cambodia's by 0.98 percent.[183] For Brazil, its economy could be 0.82 percent larger than would otherwise be the case in the 10th year after it joined the ITA.[184] Other nations—such as India, Indonesia, and Vietnam—which joined the original ITA but have yet to join the ITA expansion, would also benefit from doing so, both in terms of their ability to participate in ICT supply chains and from the ITA's ability to foster greater levels of economic growth.[185] Notwithstanding the institutional challenges the organization faces, the WTO has had a very positive impact on the global semiconductor industry, and not just through the tariff-eliminating aspects of the ITA, which have done so much to facilitate the globalization of the industry's supply chains. The WTO has also performed an important role as a dispute settlement body that has played a useful role at key points in effectively adjudicating transnational conflicts in the sector.

Maintain the WTO E-Commerce Customs Duty Moratorium. In 1995, WTO members agreed to a practice of not imposing customs duties on international electronic transmissions, with the decision to continue doing so reviewed at four-year intervals since.[186] The moratorium was up for renewal in late December 2019, but the coronavirus crisis pushed discussion back to the 12th Ministerial Conference, which was to have taken place in June 2020 in Kazakhstan, although this has also since been postponed. Maintaining the moratorium is important to the semiconductor industry, because if duties on e-commerce transmission were allowed, countries could in theory place duties on the transfer, for instance, of electronic files containing designs for semiconductors, or blueprints for semiconductor factories. This would be especially deleterious for semiconductor companies—such as AMD, Broadcom, MediaTek, and Qualcomm—which pursue fabless business models.[187] In other words, if countries were able to start applying e-commerce customs duties, it would be quite disruptive to semiconductor global value chains. While countries may be attracted to the additional income duties on e-commerce transactions could generate, studies have found that the harmful economic impact the duties would have, by hampering and thus decreasing e-commerce and data flow activity, would more than offset any benefit from the increased income from duties. For instance, the European Center for International Political Economy (ECIPE) estimated that India's economy would suffer annual economic losses of $1.9 billion in GDP, with the depressed economic activity costing over $2 billion in domestic losses; the estimated impacts for China would be over $600 billion in lost GDP and $244 billion in lost tax revenues.[188] WTO members should continue the practice of refraining from imposing duties on international electronic transmissions.

If duties on e-commerce transmission were allowed, countries could in theory place duties on the transfer, for instance, of electronic files containing designs for semiconductors, or blueprints for semiconductor factories.

Join and Expand the Comprehensive and Progressive Trans-Pacific Partnership Agreement. The roots of the CPTPP go back to the Trans-Pacific Strategic Economic Partnership Agreement originally signed as a free trade agreement (FTA) by Brunei, Chile, New Zealand, and Singapore in 2005. The United States picked up the vehicle under the George W. Bush administration as an opportunity to expand market- and rules-based trade among like-minded Pacific-region nations—and as a tonic to growing Chinese economic influence in the region—enrolling 12 nations in negotiations toward completing a Trans-Pacific Partnership (TPP) agreement. The Obama administration continued and completed the effort with a final deal in February 2016, only for the Trump administration to withdraw the United States from the deal, and the remaining 11 nations—Australia, Brunei, Canada, Chile, Japan, Malaysia, Mexico, New Zealand, Peru, Singapore, and Vietnam—to forge ahead with a CPTPP deal concluded in Tokyo in January 2018 and signed in Santiago, Chile, in March 2018.[189]

The CPTPP represents a high-standard trade agreement committing nations to trade practices that eliminate or significantly curtail tariff and non-tariff barriers; respect foreign entities' IP rights; condition state intervention in economies, especially through the activities of SOEs; and include new rules facilitating e-commerce and digital trade. A number of the provisions of the erstwhile TPP, or new CPTPP, as well as the recently completed United States-Mexico-Canada (USMCA) free trade agreement, are of particular importance to the semiconductor industry. For instance, the CPTPP includes prohibitions against localization requirements that would force businesses to build data storage centers or use local computing facilities when providing digital services; protections for proprietary software source code; prohibitions against circumventing technological protection measures (TPMs), such as encryption; a commitment to not include customs duties on electronic content or transmissions; and a commitment to cooperate on cybersecurity through coordinated national computer emergency response teams.[190] The USMCA includes additional provisions such as protections for algorithms and encryption keys and expanded trade secret protections, including criminal penalties for willful trade secret theft.[191]

The United States should join the CPTPP and bring like-minded economies, including those of South Korea and Taiwan, into the agreement as well. The United States should also leverage the USMCA—as well as the Pacific Alliance, an FTA between Chile, Colombia, Mexico, and Peru—as a platform for deeper trade integration in the Americas, in part because nations in the Americas could play a greater role in their integration into global ICT and semiconductor supply chains.

Expand Subsidies Disciplines at the WTO. China has become competitive in many advanced-technology sectors—from solar panels and wind turbines to telecom equipment to semiconductors—in part due to Chinese government subsidies, often provided to SOEs. For instance, 95 percent of Chinese firms in tech industries received R&D subsidies in 2015, with those subsidies accounting for 22 percent of firms' R&D investments.[192] China "spent or loaned $30–$40 billion to establish its current position as the world's leader in both solar and wind turbine technologies."[193] As noted, China's "Guidelines to Promote the National Integrated Circuit Industry" has called for $150 billion in funding from Chinese central, provincial, and municipal governments to establish a closed-loop semiconductor ecosystem in China.

The United States should work with like-minded nations (including through the trilateral framework with the European Union and Japan) and at the WTO to update its rules to impose much stiffer conditions on, and penalties for, aggressive industrial subsidization.[194] This should start with clarifying the definition of a "public body," extending it to include state-influenced activities of entities such as SOEs and private firms.[195] Rules should obligate the subsidizing country to prove that a given subsidy does not inflict harm on others. Like-minded nations should focus on achieving a significant increase in global subsidies transparency, including insisting upon timely and complete notification of subsidies and establishing a presumption of prejudice toward subsides not timely notified.[196] The countries should also designate an annual meeting between WTO members and the WTO appellate body to discuss patterns and challenges pertaining to excessive use of subsidies.

Insist on market access reciprocity in digital government procurement activity: Core bedrock principles of the WTO include national treatment, non-discrimination, and reciprocity. Nations—especially developed ones that in part can meet that definition as evidenced by their capability to invest hundreds of billions of dollars into one of the world's most-advanced industries—that don't offer reciprocal market access are fundamentally failing to meet their WTO responsibilities (let alone to adhere to the spirit of the institution). When that happens, countries are justified in recognizing and pushing back against such outcomes. This is exactly why the European Union is now considering developing a reciprocal International Procurement Instrument that would ensure the access Europe offers to foreign countries' enterprises in government procurement activity is mirrored by the access rights their own companies enjoy in countries such as China, or even the United States.[197] Building upon the European Union's effort to craft an International Procurement Index, like-minded nations should collaborate with one another to catalog where other nations are denying or restricting their enterprises' market access in government procurement of digital goods or services and—if they cannot collectively negotiate an accommodation of those practices—introduce similar, reciprocal restrictions in their own markets.

Consider forming a Global Strategic Supply Chain Alliance. Taking a page from the North Atlantic Treaty Organization (NATO), some have called for like-minded nations to come together to form a Global Strategic Supply Chain Alliance that could collectively address security needs with respect to critical strategic items.[198] Such a GSSCA would organize certain key industries for the benefit of its member states, with members agreeing to develop supply chains within the GSSCA to the exclusion of similar items from non-member states. Such an alliance could be organized around particular items or products, such as 5G networks, rare earth metals, active pharmaceutical ingredients, or perhaps a key tool or component in the semiconductor supply chain. The theory behind the GSCCA structure would be "an economically oriented calculus that combines risk assessment at a supply chain level with a strategic overlay."[199] While an open approach to trade and globalization in the semiconductor sector (and the broader global economy) outlined at the start of this report is certainly preferable, such a structure could become necessary in the future should some nation(s) seek to corner certain key inputs or supplies to the detriment of the international supply chain or other nations.

Develop an Allied Response to the Evolving Global Trade Landscape. The United States should work with like-minded nations to develop initiatives to address the changing global trade and economic landscape. The elements to do so already exist. For instance, the Trump administration's Indo-Pacific strategy seeks to work with regional allies to advocate for free, fair, and reciprocal trade; open investment environments; good governance; and freedom of the seas.[200] Since an inaugural Indo-Pacific Business Forum in July 2018, U.S. government engagement has catalyzed private-sector investment in Indo-Pacific infrastructure, supported by $2.9 billion through the Department of State and USAID, as well as hundreds of millions more through other agencies, including the U.S. Millennium Challenge Corporation (MCC) and the Overseas Private Investment Corporation (OPIC).[201] Meanwhile, the U.S. International Development Finance Corporation, created by the Better Utilization of Investments Leading to Development (BUILD) Act in 2018, will be providing $60 billion in development financing to attract more private-sector investment into global emerging markets. In May 2020, the U.S. Export-Import (Ex-Im) Bank launched a "Strengthening American Competitiveness Initiative" that seeks "to advance U.S. comparative leadership in the world with respect to China and supporting America's innovation, employment, and technological standards through supporting U.S. exports." Through a new, congressionally mandated initiative, "The Program on China and Transformational Exports," Ex-Im is to allocate not less than 20 percent of its total financing authority annually (at least $27 billion in FY 2020), for U.S. exports that compete with China, including for exports of specific advanced technologies including semiconductors; AI and high-performance computing; 5G and other wireless communications; renewable energy; and biotechnology and biomedical sciences.[202]

Elsewhere in the region, Taiwan's "The New Southbound Policy," launched in May 2016 by President Tsai Ing-wen, aims to expand Taiwan's trade, investment, and diplomatic relations with countries in South and Southeast Asia.[203] Likewise, South Korean President Moon Jae-in has articulated a New Southern Policy that seeks to deepen trade and economic relationships with ASEAN (Association of Southeast Nations) countries, and Japan has expressed a Free and Open Indo-Pacific Vision (FOIP).[204]

The United States should continue to work with these nations on collaborative international development aid/assistance, development finance support, and export credit initiatives to encourage nations in the Indo-Pacific region to select digital technologies, solutions, and platforms from vendors from like-minded nations. A promising start is OPIC's launch of the Blue Dot Network, a multi-stakeholder initiative coalescing like-minded governments, the private sector, and civil society under shared standards of global infrastructure development.[205] But while programs such as Ex-Im's "Strengthening American Competitiveness Initiative" represent a step in the right direction, they could potentially be more impactful if they worked in lockstep with initiatives from like-minded countries, especially if developing nations in the region are considering significant national-scale digital infrastructure implementations—such as of 5G networks, smart-city implementations, or smart-grid networks—where collaborative bids from teams of enterprises from like-minded nations could be supported by common development finance or export credit assistance from their respective governments.

CONCLUSION

Semiconductors are foundational to both many countries' economic and national security, which is why it's understandable that policymakers want to capture as much value added as possible from the industry, whether in R&D, design, fabrication, or ATP. Competition to develop and attract this work is healthy—if done fairly. But countries need to focus first on policies that make their nations an attractive environment for semiconductor and other advanced-technology sectors—such as providing a strong IP regime, rule of law, and regulatory environment; ensuring deep pools of skilled talent; and providing a favorable tax and investment environment. And second on specific policies, programs, and initiatives to bolster their semiconductor sectors specifically. This includes robust, sector-focused R&D programs, such as Manufacturing USA institutes, that can support development of advanced semiconductor manufacturing process technologies, and federal investment in long-term transformative moonshot efforts. To the extent other nations are providing specific investment incentives to attract semiconductor manufacturing activity—such as state or federal tax breaks; free, discounted, or subsidized land, utilities, or infrastructure; and related financial incentives—then, as the CHIPS Act envisions, it's appropriate for the United States to introduce programs that can help offset such foreign incentives. That's important when foreign government incentives may be responsible for as much as 40 to 70 percent of the higher total cost of ownership of semiconductor fabs in the United States compared with foreign nations.[206] However, it does not justify calls for Buy American policies or explicit localization of semiconductor manufacturing in the United States. The United States (and other like-minded nations) are on strongest ground when they use incentive-based policies to spur greater levels of semiconductor R&D and production to occur in their nations.

Semiconductors represent one of the world's most globalized industries, and embracing that dynamic has been critical to the competitiveness of leading semiconductor companies. Countries that would seek self-sufficiency in the sector, especially through employing mercantilist means, inflict considerable damage on the global industry, and threaten to undermine their own competitiveness over the long-term. Nevertheless, some nations, such as China, appear to be pursuing such a path, and it's important that like-minded nations align to ramp up cooperation, both to push back on unfair trade practices and to collectively boost their own competitive.

Competition in this capital-intensive, globally mobile sector, like any other, needs to be predicated on private-sector, enterprise-led, market-based, rules-governed terms in accordance with the foundational WTO principles of national treatment, reciprocity, and non-discrimination.

This is a standard all WTO member nations have committed to upholding. Moreover, this is critical if policymakers want to maximize both innovation and the ability of the sector to continue producing breakthrough technologies for the world's benefit. Looking ahead, given the extreme cost and complexity involved in innovating in the semiconductor sector, no company, or even country, can afford to go it alone; the immense challenges involved require collaboration from like-minded nations if they are to be met. Given this, nations willing to explore new ways to foster collaboration in this industry stand a better chance of succeeding in the future than if they each try and go it alone in trying to develop their own semiconductor industry autonomously. The semiconductor sector promises to produce tremendous innovations for generations to come—but these will arrive faster and with greater impact if like-minded nations find constructive ways to work together.

Acknowledgments

The author wishes to thank Dr. Robert Atkinson and Nigel Cory for providing input to this report. Any errors or omissions are the author's alone.

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