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24-3 Semiconductors and Modern Industrial Policy

Chad P. Bown and Dan Wang

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ABSTRACT

Semiconductors have emerged as a headline in the resurgence of modern industrial policy. This paper explores the political economic history of the sector, the changing nature of the semiconductor supply chain, and the new sources of concern that have motivated the most recent turn to government intervention. It also explores details of that turn to industrial policy by the United States, China, Japan, Europe, South Korea, and Taiwan. Modern industrial policy for semiconductors has included not only subsidies for manufacturing, but also new import tariffs, export controls, foreign investment screening, and antitrust actions.

Chad P. Bown is Reginald Jones Senior Fellow at the Peterson Institute for International Economics, Washington, DC.

Dan Wang is a Fellow at the Paul Tsai China Center, Yale Law School, New Haven, Connecticut.

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INTRODUCTION

Semiconductors, also known as chips or integrated circuits, are the tiny pieces of machine-crafted silicon that play an essential role in all digital technologies. These include everything from microwaves and toasters to smartphones and 5G communications networks, as well as automobiles, advanced weapons systems, and emerging tools for artificial intelligence. Semiconductors are, in short, intertwined with technological leadership, economic prosperity, jobs, and even national security.

For governments, the semiconductor industry has been an irresistible target for industrial policy. The sector is science-based and fast-moving. It has vast capital requirements: a new semiconductor fabrication plant, or "fab," or "foundry," now costs on the order of $20 billion. Learning-by-doing is important in the manufacturing process, having the potential to spill over to other parts of the economy and thus creating a possible efficiency role for government intervention. Thus, with an industrial policy based on subsidies for research and development or for capital/construction costs—or perhaps even for short-term protection from import competition—policymakers hope to gain a lasting first-mover advantage for their local chip sector.

Some policymakers may hope for an even greater ultimate prize. The origins of semiconductor manufacturing in Silicon Valley have become the canonical example of "agglomeration externalities." For economists, this can describe the phenomenon of economies of scale at the level of local industry: that is, industry average costs falling as more output was produced. In an agglomeration economy, knowledge grows and spreads as workers share ideas within and across firms. Multiple companies enjoy access to the same local pool of specialized workers and input suppliers, as well as access to customers for cutting-edge products. In Silicon Valley, over time this mixture would expand to include upstream toolmakers, chip manufacturers themselves, downstream users like computer and telecommunications companies, and now also digital platforms and software companies at the forefront of artificial intelligence. The success of Silicon Valley is one that many other countries would like to replicate. They too want a self-sustaining ecosystem for generating, producing, and then re-generating cutting-edge technologies.

But modern industrial policy is also grappling with one other central challenge—that these agglomeration externalities may also lead to the excessive geographic concentration of semiconductor manufacturing. Something has arguably gone too far. Today's heightened risk of localized shocks stemming from climate change (e.g., extreme storms or droughts), public health emergencies (e.g., shutdowns tied to the COVID-19 pandemic), or even geopolitical tensions (e.g., blockades, invasions, or war) have spurred policymakers into seeking more diversified sources of production.

In this working paper, we begin with a review of the early US dominance of the semiconductor industry, and then move to globalization of the sector in the 1980s and 1990s. We consider three main traits that define the modern industry: the rise of the fabless foundry model in which chip design and manufacturing are done by different firms, the fragmentation of the semiconductor supply chain, and the global shifts in demand for and supply of semiconductors. We then describe two recent issues that are driving concerns about the chip sector: the rise of the semiconductor industry in China and the riskiness of concentrated production in certain other parts of East Asia. This has implications beyond the standard industrial policy topics of market and technological leadership, and it raises issues related to risks of supply disruptions and weaponizing trade dependencies, as well as the future use of semiconductors in areas like weapons, surveillance, and artificial intelligence.

We then review how governments are implementing industrial policy. In the United States, a primary tool is the CHIPS Act of 2022—formally called the Creating Helpful Incentives to Produce Semiconductors Act. Meanwhile, China and other major economies in East Asia and Europe are deploying industrial policies of their own. Though subsidies and import tariffs have retained importance in the activist government tool-kit, additional policies like export controls, foreign investment screening, and even merger reviews are increasingly used as well. In the conclusion, we point out that the semiconductor industry, despite its public prominence, is under researched. We suggest some of the questions and topics that might usefully be investigated as the current global wave of semiconductor industrial policy proceeds.

EARLY US DOMINANCE OF THE SEMICONDUCTOR INDUSTRY

Semiconductor chips evolved from the transistor, which was invented in the late 1940s in New Jersey at Bell Labs—the research arm of American Telephone and Telegraph (AT&T)—by a team of scientists who would later win the 1956 Nobel Prize in physics. Packing large numbers of transistors onto a small chip ultimately resulted in the integrated circuit etched on a silicon wafer, and packing more and more transistors onto those integrated circuits meant faster and more powerful electronic applications. By 1965, Gordon Moore, who later founded Intel, would famously predict that the number of transistors on a chip would double roughly every two years, something that became known as Moore's Law and has held true for half a century (Roser, Ritchie, and Mathieu 2023).

In this early period, the primary form of US industrial policy toward semiconductors was through direct purchases for the military and space programs—the destination for about half of US production of integrated circuits in the early 1960s (Tilton 1971, Table 4-8). However, these forms of industrial policy became relatively less important as private sector demand for semiconductors surged. Pocket calculators, for example, was an early driver of chip demand. Semiconductors became a standard input into telecommunications equipment, consumer electronics, computers, and more.

Through the 1970s, American firms dominated the semiconductor industry. Texas Instruments, National Semiconductors, Motorola, and Intel were among the top five firms globally in 1980, by revenue. Yet, even the numbers shown in Table 1 underrepresented the size of US semiconductor manufacturing, which featured another set of vertically integrated companies that made chips only for their in-house needs. These "captive" semiconductor manufacturers that produced for internal demand included AT&T and IBM—at the time, the latter was one of the largest semiconductor manufacturers in the world (USITC 1993, 7). Because their business model did not involve arm's-length sales, these companies were often omitted from industry lists defined in terms of revenues. Companies like Intel or Motorola that sold semiconductors on the open market were "merchant" firms. Some, like Texas Instruments, did both.

Table 1
Top 10 global semiconductor firms, by sales revenue, 1980–2020

Ranking	1980	1990	2000	2010	2020
1	Texas Instruments	NEC (Japan)	Intel	Intel	Intel
2	National Semiconductor	Toshiba (Japan)	Samsung (South Korea)	Samsung (South Korea)	Samsung (South Korea)
3	Motorola	Intel	NEC (Japan)	TSMC (Taiwan, foundry)	TSMC (Taiwan, foundry)
4	Philips (Europe)	Hitachi (Japan)	Texas Instruments	Texas Instruments	SK Hynix (South Korea)
5	Intel	Motorola	Toshiba (Japan)	Toshiba (Japan)	Micron
6	NEC (Japan)	Texas Instruments	STMicro (Europe)	Renesas (Japan)	Qualcomm (fabless)
7	Fairchild Semiconductor	Fujitsu (Japan)	Motorola	SK Hynix (South Korea)	Broadcom (fabless)
8	Hitachi (Japan)	Mitsubishi (Japan)	Micron	STMicro (Europe)	Nvidia (fabless)
9	Toshiba (Japan)	National Semiconductor	Hyundai (South Korea)	Micron	Texas Instruments
10	Mostek	Philips (Europe)	Hitachi (Japan)	Qualcomm (fabless)	Apple* (fabless)

*Custom devices for internal use.

Note: Shaded companies are domiciled in the United States. In 2001, SK Hynix completed its separation from Hyundai. In 2009, NEC and Renesas Technology merged, forming Renesas Electronics. In 2018, Broadcom redomiciled from Singapore to the United States.

Sources: Compiled by the authors from Brown and Linden (2009, Table 1.1); IC Insights Research Bulletin (2012, 2021).

THE JAPANESE CHALLENGE, ACTIVIST INDUSTRIAL POLICY, AND THE RISE OF A GLOBAL SEMICONDUCTOR MARKET

While European companies like Philips had long been major players in the sector, the emergence of Japanese firms in the 1970s and 1980s posed the first major threat to American chipmakers' dominance of the US semiconductor market.[1] Two differences between the Japanese and US models stood out.

One difference involved the role of government, with Japan taking a more activist form of industrial policy toward the semiconductor sector. Japanese government support included industry tax breaks—since replicated elsewhere—as well as facilitation of a consortium of domestic firms that would pool resources in an effort to prevent redundant spending on research and development (R&D), through the Very Large Scale Integrated Circuits (VLSI) project of 1976–1979 (Okuno-Fujiwara 1991).

A second difference stemmed from industrial structure. Many Japanese semiconductor firms were vertically integrated—similar to, say, IBM or AT&T in the United States—and thus benefited from internal demand for their chips. However,

1 This section draws heavily from Irwin (1996), the seminal political-economy study of the US-Japan trade dispute over semiconductors during the 1980s.

the vertically-integrated American suppliers mostly kept their production in house, worried about antitrust authorities questioning the terms of their sales to competitors. Unlike their American counterparts, Japanese firms also sold their semiconductors on the US market. Meanwhile, the other half of the US chipmaking industry that only manufactured for arm's-length sales found it difficult to penetrate the Japanese market, where demand was driven by those vertically integrated Japanese companies. Some "captive" US semiconductor firms like IBM did have foreign direct investment operations in Japan and accessed the Japanese market in this way (Irwin 1996).

Furthermore, Japanese firms were part of *keiretsu*, or business conglomerates. These included affiliations with a large bank that helped facilitate investments into capital expenditure—which Japanese firms did much more than US firms during this period (OECD 1992, 146–147). Access to credit would allow Japanese companies to expand production even during market downturns, which was important for an industry characterized by boom-bust cycles, and not something that American companies could match (Irwin 1996; Hoshi, Kashyap and Sharfstein 1990).

Exports from Japan became ever more visible in the US economy during this time, starting with less technologically sophisticated sectors like clothing and footwear in the 1960s, and then in the 1970s and 1980s proceeding to steel, consumer electronics, automobiles, and ultimately chips. Japan's increasing industrial competitiveness stemmed from many sources, including its very high rates of domestic saving and investment as well as elevated US interest rates and a strengthening US dollar that made imports from Japan relatively cheaper. When the United States began to run a large and growing trade deficit in the 1980s, Japan was the country with the largest bilateral surplus. Imports from Japan were a tremendous source of trade conflict at the time, leading to alarmist predictions of decline for the entire US economy (Prestowitz 1988, Thurow 1992). This culminated into the United States pursuing "aggressively unilateral" trade policy, including toward Japan (Bhagwati and Patrick 1990; Bergsten and Noland 1993).

For semiconductors, the result was a highly interventionist US policy, in which the nature of industrial policy shifted to attempts to manage and regulate foreign trade. Under the threat of US import tariffs, Japan "voluntarily" agreed in the US-Japan Semiconductor Trade Agreement of 1986 to limit exports to both the US and third country markets. The Japanese government also "voluntarily" agreed to expand Japan's *imports* of chips—specifically, American firms were to supply 20 percent of the Japanese market by 1992. When goals were not met, the US government retaliated with import tariffs, including on Japanese computers and televisions that used semiconductors as inputs. Such aggressive use of trade policy against an ally was unusual and partly made possible because of Japan's reliance on the United States for military protection.

The US government also decided to emulate some elements of the Japanese approach. For example, the US Department of Defense provided $100 million annually for five years beginning in 1988 to SEMATECH (SEmiconductor Manufacturing TECHnology), a public-private partnership. Though its performance would face mixed reviews, SEMATECH involved 14 US-based semiconductor firms forming a consortium designed to share the burden of R&D costs that some felt were holding back the US industry (Irwin and Klenow 1996).

One short-term impact of the US-Japan Semiconductor Trade Agreement was to stabilize semiconductor prices, which had been an objective of US semiconductor firms. But using bilateral trade policy as an industrial policy tool to push for higher price levels also created opportunities for chip companies in other economies—who had often benefited from their governments' industrial policies—to enter the market profitably.

For example, Taiwan Semiconductor Manufacturing Corporation (TSMC) emerged in 1987 as the world's first contract manufacturer of chips designed by other companies. The Taiwanese government provided $100 million to help TSMC construct a foundry that would focus on manufacturing chips designed by Philips and other companies (Landler 2020; Chang and Hsu 1998). Other firms also invested in Taiwan at the time, including Texas Instruments. All told, Taiwan's share of US semiconductor imports doubled between 1989 and 1999, from 4.5 percent to 9 percent.[2]

In South Korea, Samsung, Goldstar and Hyundai—the latter two would one day combine to become part of today's SK Hynix—also emerged as global competitors in making semiconductors.[3] During this era, the South Korean government provided support to conglomerate *chaebols*, a form of industrial structure similar to Japan's *keiretsu*: for example, Samsung and Hyundai received subsidized credit (Kim 1998). South Korea's share of the US import market for semiconductors grew from 6 percent in 1987 to 16 percent by 1999. By 2000, Samsung and Hyundai had joined the ten largest semiconductor companies in the world (again, see Table 1). They started by focusing on "memory" chips, which store data for retrieval rather than "logic" chips that process data. It's noteworthy that Japan and South Korea each developed their chip industries via mastery of memory chips. Industry success has long been characterized by process technology improvements, where learning-by-doing meant increasing "yields," or getting more usable chips from each batch of production. In a study of dynamic random access memory (DRAM) over 1974–1992, Irwin and Klenow (1994) found per unit production costs fell 20 percent every time cumulative output doubled (for additional discussion of learning-by-doing for semiconductor production, see also Baldwin and Krugman 1988; Dick 1991).

In the United States, Europe and Japan, the new competition from South Korea and Taiwan resulted in renewed industry demands for import protection. Though Micron had licensed some of its technology to Samsung in the early 1980s, in 1992 it changed tack and filed an antidumping petition against the Korean firm, seeking import tariffs and alleging injury caused by underpriced chips. Around the same time, Motorola's UK subsidiary and the German firm Siemens asked for similar protection in Europe from the Korean memory chipmakers. In 1997, Micron demanded (and received) US antidumping duties on imports of Taiwanese semiconductors. Following the Asian financial crisis in the late 1990s, Micron and its affiliates also requested and received anti-subsidy (countervailing) duties on Korean memory imports across three different markets—the United States, Japan, and European Union.

2 This section draws from the trade and policy data presented in detail in Bown (2020).

3 In 1995, Goldstar changed its name to LG Electronics, which then merged with Hyundai in 1999 to form Hynix. In 2012, Hynix partnered with SK and changed its name to SK Hynix.

The memory segment of the semiconductor industry was also consolidating heavily, with Micron, Samsung, Hynix, and Infineon (a spinoff of Siemens) dominating the market by the early 2000s. This led to conflicting US policy signals. While one part of the federal government was worried about subsidized imports being priced too low, American antitrust authorities became simultaneously concerned that memory chip manufacturers were colluding to raise prices, hurting computer companies such as Dell, Hewlett-Packard, Apple, and IBM. Between 2004–2005, Samsung, Hynix and Infineon all pled guilty to fixing memory chip prices and paid criminal fines, while firm executives served prison terms (US DOJ 2005).

Any industrial policy history of the semiconductor sector from this era runs a risk of sounding like nothing but trade barriers and disputes. But in the mid-1990s and early 2000s, two trade-facilitating policy developments would also ultimately serve as a counterweight to help globalize the industry's supply chains. First, these major economies implemented important international agreements featuring a general reduction of import tariffs for semiconductors and critical inputs, such as semiconductor manufacturing equipment. This included the 1997 Information Technology Agreement, a deal to cut tariffs to zero on a wide range of high-tech products, as well as China and Taiwan joining the World Trade Organization (WTO), which locked in their low tariffs, in 2001 and 2002, respectively. The second policy innovation involved the TRIPs (Trade Related Aspects of Intellectual Property Rights) Agreement, implemented as part of the establishment of the WTO in 1995. Improved protection of patents and other trade secrets would help facilitate the fabless-foundry model—one firm licensing its technology to another firm for manufacturing purposes, without fear that the first firm would lose its intellectual property to another of the manufacturer's clients.

THE MODERN SEMICONDUCTOR INDUSTRY: THREE CHARACTERISTICS

The semiconductor industry changed in terms of how and where chips would be produced. Here, we emphasize three characteristics of the modern industry that subsequently shaped the context for today's policymakers.[4]

The Rise of the Fabless Foundry Model

The structure of the semiconductor industry has evolved considerably over the past three decades. Begin with memory chips—which store data—which continued to make up roughly 23 percent of global industry sales in 2022 (SIA 2023a). The most noticeable feature of the memory chip segment is its continued consolidation: Samsung, SK Hynix, and Micron, for example, currently make up nearly all of the lucrative DRAM market. Furthermore, memory chips are the most commoditized of semiconductor technologies: products from Samsung or Micron are largely interchangeable, and some memory chips are even sold on a spot market. Still, they are likely the most complex of all products that are commoditized.

4 For book-length treatments of the evolution of the semiconductor industry, see Brown and Linden (2009) and Miller (2022).

Aside from memory, the rest of the semiconductor market includes logic, analog, and a variety of other kinds of chips that perform different functions. These types of semiconductors are also sometimes characterized by their vintage. At one extreme might be the latest graphics processing unit (GPU) chip that is needed to run today's most powerful large language model for artificial intelligence. At the other extreme are "legacy" or "mature" semiconductors that have been around for a while. Though firms may not require the latest technology to manufacture these older types of chips, the products remain complex. A semiconductor that goes into an automobile that powers a window, for example, may be little different from one of ten years ago. Yet, it has other critical characteristics—such as reliability and durability—allowing it to survive extreme temperature changes over long periods of time without replacement.

For the non-memory segment of the market, integrated device manufactures such as Intel and Texas Instruments remain important players. Nevertheless, perhaps the greatest change in industry structure has been the rise of the fabless-foundry model. Some companies (especially in Silicon Valley) have decided to focus solely on the design of logic chips, while contracting with specialized foundries (mostly in Asia) to manufacture them. The most prominent foundry company is Taiwan's TSMC, the industry pioneer, which emerged as a top 10 firm by revenue by the 2000s (as shown in Table 1). Other examples of such "pure-play" foundries include UMC (Taiwan), GlobalFoundries (United States), and SMIC (China). A large share of their expenditures involves the physical plants and capital equipment needed to run state-of-the-art facilities. Again, by the 2020s, the cost of building and equipping a leading-edge fab was above $20 billion.

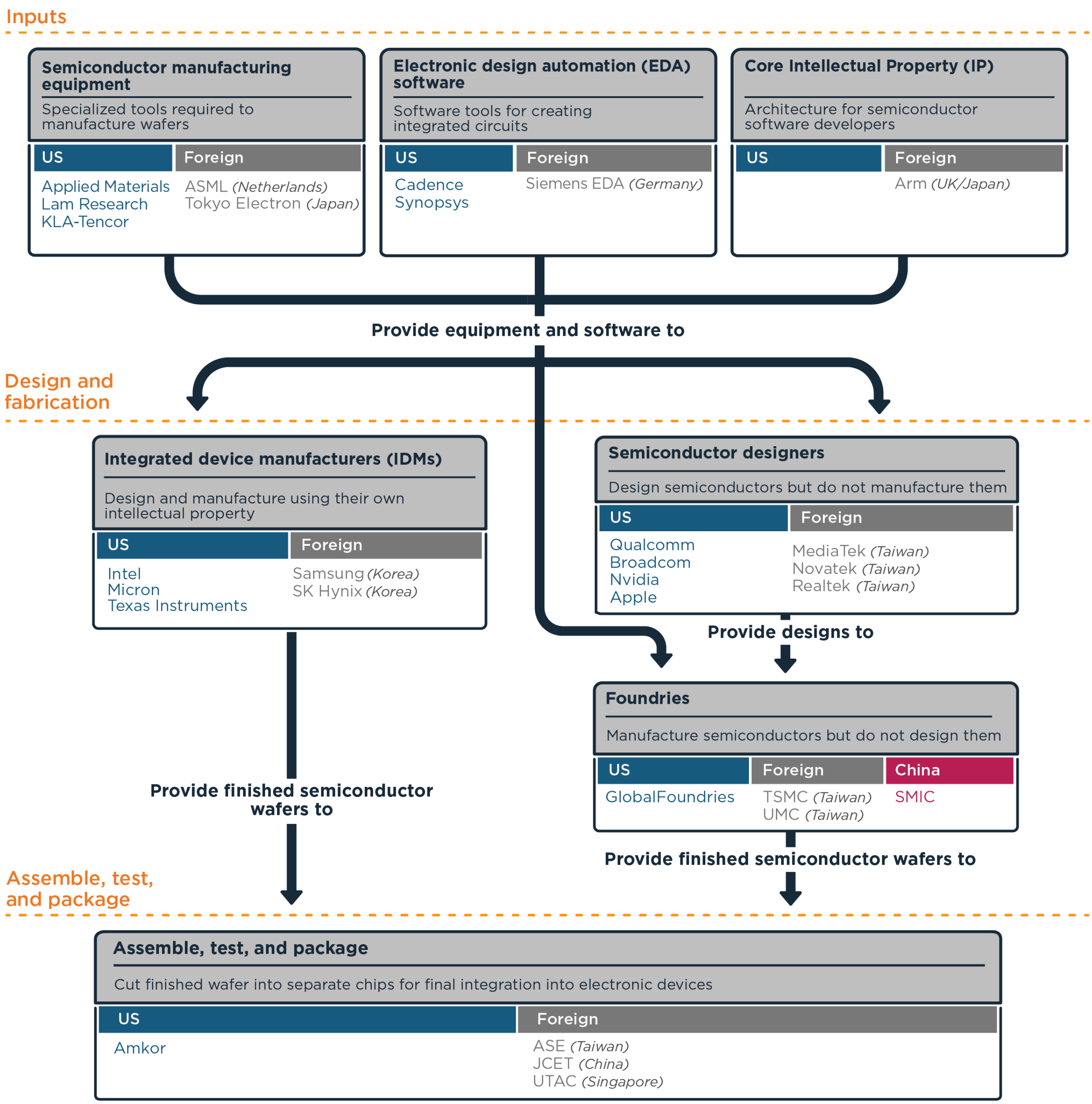
The complement to foundries are "fabless" chip companies (see Figure 1). They focus only on design. For example, Broadcom developed chips for modems, routers and telecommunications networks, while Qualcomm designed semiconductors for smartphones and other devices (Nellis and Mehta 2023). Apple has become a major semiconductor player in its own right by replacing chips from Intel, Qualcomm, and others in its computers and mobile phones. Nvidia has become prominent for its GPU chips that are in demand with the growth of artificial intelligence applications (Waters 2023). These design companies devote the bulk of their costs to R&D while letting the foundries worry about capital-intensive manufacturing. By 2020, four of the top ten semiconductor firms by revenue were fabless. But without the emergence of contract manufacturers such as TSMC, fabless firms likely would not exist.

THE FRAGMENTATION OF SEMICONDUCTOR SUPPLY CHAINS

Beyond design and manufacturing of semiconductors, Figure 1 illustrates other critical elements of the modern semiconductor supply chain. For example, the last step involves taking a finished wafer and putting it through a process known as "assembly, test, and package" by cutting the wafer into separate chips for final integration into electronic devices. This phase is relatively worker-intensive and thus is not only often outsourced to a different company, but is also often offshored to a labor-abundant country where wage costs are lower. Indeed, the assembly, test, and package segment was one of the first parts of the semiconductor supply chain to be moved overseas in the 1960s, when Fairchild Semiconductor set up such a process in Hong Kong.

Figure 1
Modern semiconductor manufacturing is a globally integrated, multi-stage process

The stages and examples of companies involved in the semiconductor design and manufacturing supply chain



Note: Examples of companies are illustrative.
Source: Constructed by the authors.

The upstream direction of the supply chain includes key input providers. One input is the software from electronic design automation firms, currently dominated by two US-based companies, Cadence and Synopsys, as well as the German firm Siemens EDA.[5] Many semiconductor companies are also reliant on the intellectual property input—or “Core IP”—of Arm, a firm headquartered in the UK-owned by a Japanese financial institution (Softbank).

For physical inputs, five companies—three in the US (Applied Materials, Lam Research, KLA-Tencor), one in the Netherlands (ASML), and one in Japan (Tokyo Electron) dominate the provision of capital equipment used in these $20 billion fabs. ASML plays an outsized role as the only firm to make the extreme ultraviolet lithography equipment required to produce the most advanced semiconductors, including those used in artificial intelligence and weapons systems (Bounds 2023; Bradshaw and Gross 2023).

Geography of Semiconductor Manufacturing

While the overall semiconductor supply chain meanders around the world, the physical manufacturing at foundries and the tasks of assembly, test, and package have gravitated both toward each other and toward the location of downstream demand for many of those chips. The Semiconductor Industry Association (SIA 2023a) estimates that 70 percent of end users of chips are companies making consumer electronics, computers, and telecommunications equipment. Assembly of such products became increasingly concentrated in China over the 2000s, as firms like Apple hired contract manufacturers to put together iPhones and other devices using low-cost labor.

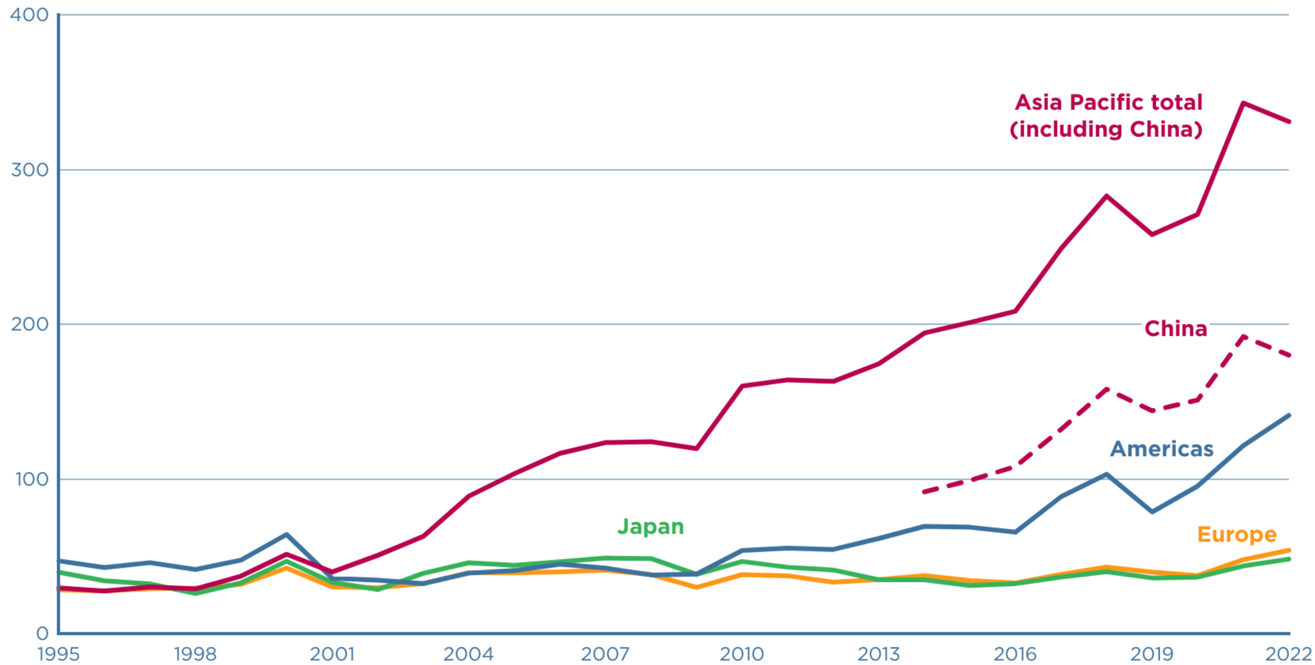
Figure 2 illustrates the geographic distribution of demand emanating from such electronic equipment end-users. By 2020, 62 percent of demand from these end-users was located in Asia, and 34 percent of global demand came from China alone. Furthermore, most of the major US-headquartered chipmakers—both integrated device manufacturers and fabless designers—counted China as a major destination for their sales: for example, China accounts for roughly 30 percent of semiconductor sales of Intel, Broadcom, and Nvidia, and half or more of sales of Texas Instruments and Qualcomm (based on authors’ calculations from annual 10K company reports).

On the supply side, the location of semiconductor manufacturing also became very concentrated in East Asia, as shown in Figure 3. As a byproduct, the US share of global semiconductor manufacturing capacity fell dramatically—from 37 percent in 1990 to 12 percent in 2020. The United States was not alone: Europe experienced a similarly sizeable decline in its share of global manufacturing; Japan’s share also fell. However, US firms still play a very important role in the global semiconductor industry. For chip production in Taiwan by TSMC, for example, the foundry is often manufacturing chips designed by American firms like Qualcomm and Nvidia. Also, American-headquartered companies that continued to manufacture chips have also expanded outside of

5 In 2017, Siemens acquired what was then called Mentor Graphics—a firm focused on electronic design automation tools for chip-making headquartered in the United States—and renamed it Siemens EDA in 2021.

Figure 2
China has become a major source of demand for chips

Electronic equipment maker purchases of semiconductors, billions USD, 1995–2022



Notes: China-specific data are available only since 2014.
Source: SIA (2023a).

the United States through foreign direct investment—like Intel (Ireland, Israel) and Micron (Japan, Singapore, Taiwan)—either by building plants or by acquiring foreign facilities.

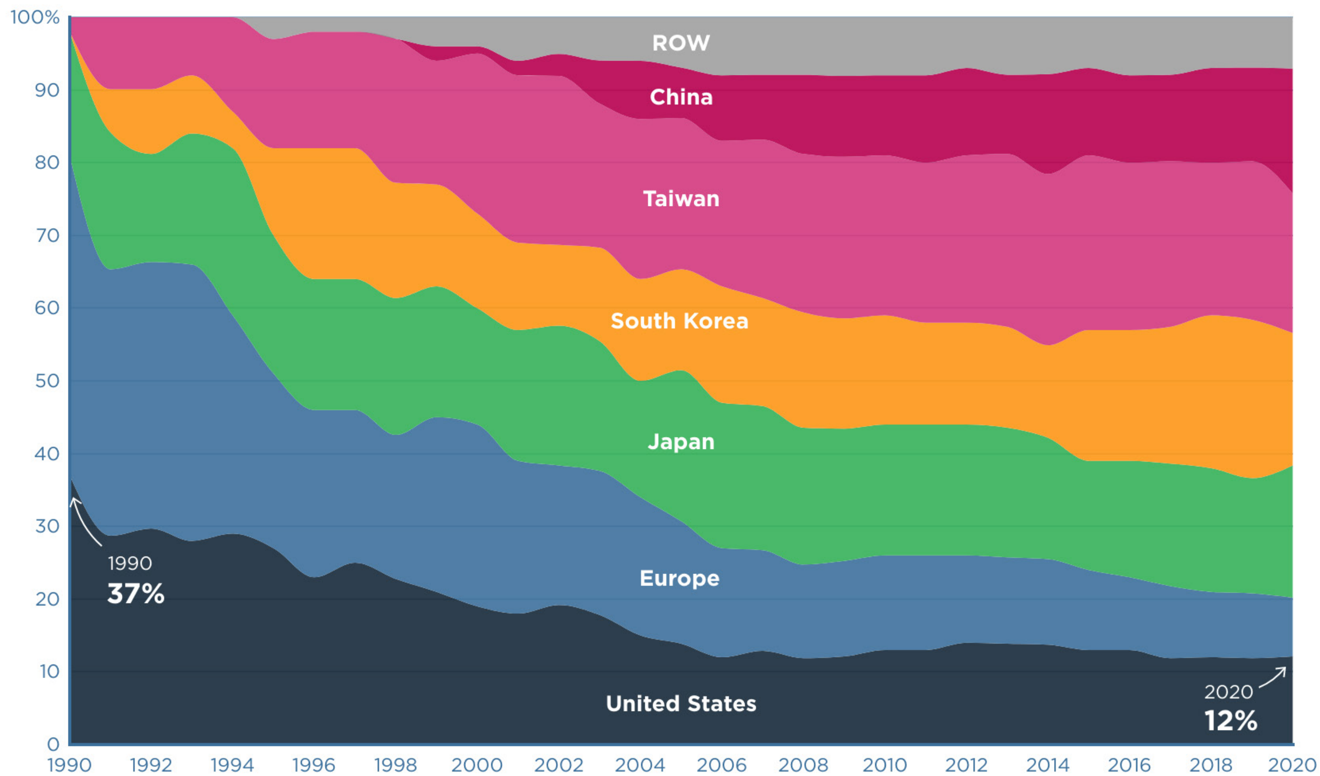
The increasing concentration of manufacturing in Asia was not due to only market forces: foreign industrial policy continued to play a role. The SIA, for example, argued in 2020 that it was 30 percent more costly to operate a fab in the United States relative to Taiwan or South Korea and up to 50 percent more costly than in China. SIA also estimated that 40–70 percent of that cost differential was due to relatively higher foreign government subsidies (Varas et al. 2020, pp. 14–20).[6]

Overall, US-headquartered firms continued to play essential roles in the global semiconductor industry. Intel remains one of the leading chip manufacturers, and four American fabless firms also made the top 10 of all semiconductor companies in 2020 by revenue. Other US companies dominated

6 The Semiconductor Industry Association is certainly not a dispassionate observer. However, whereas the SIA of the 1980s was clearly an industry association dominated by American semiconductor manufacturing firms, by the 2020s, its membership had evolved considerably. In 2023, SIA counted among its members integrated device manufacturers (Intel, Micron), fabless firms (Broadcom, Qualcomm, Nvidia), pure-play foundries (GlobalFoundries), equipment manufacturers (Applied Materials, Lam Research, KLA-Tencor), and electronic design automation tool providers (Cadence, Synopsys). SIA also had international members including TSMC, Samsung, SK Hynix, Infineon, NXP, Arm, Tower, and ASML (SIA Members, https://www.semiconductors.org/about/members/, accessed December 31, 2023).

Figure 3
Over time, the supply of semiconductor manufacturing capacity shifted toward Asia

Global manufacturing capacity by location, percent, 1990–2020



Notes: Values for 2020 are estimates.
Source: Varas et al. (2020, exhibit 2).

electronic design automation tools, and a third set provided much of the most essential semiconductor manufacturing equipment. Yet, the reduced share of chip manufacturing plants has proved worrisome for US policymakers.

CURRENT ISSUES IN THE GLOBAL SEMICONDUCTOR INDUSTRY: CHINA AND THE CONCENTRATION OF PRODUCTION

By the mid-to-late 2010s, the emerging global semiconductor industry was raising two interrelated sets of risks for many politicians: What about China? What about the increasing geographic concentration of production for the most advanced chips?

China

The Chinese government has been blatant about its desire to achieve self-sufficiency and technological leadership across a range of industries. Semiconductors is perhaps the most critical sector in which China is neither self-sufficient nor much of a technological leader (Wang 2023a). In 2014, the State Council developed its "Guidelines to Promote the Development of the National Integrated Circuit Industry," which established major funding for domestic chip companies. Beijing also revealed the "Made in China 2025" industrial policy in 2015, which set aggressive numerical targets for the future market shares of Chinese chip firms in China as well as globally, heightening concerns of policymakers elsewhere.

China's industrial policies for semiconductors were also now taking place in a changing geopolitical climate under President Xi Jinping. Flashpoints included China's gradual subjugation of Hong Kong, its military provocations through the shipping lanes of the South and East China Seas, its increasingly aggressive "wolf warrior" diplomacy, and its intention of annexing Taiwan (Harrell, Rosenberg, and Saravalle 2018). Beijing's "Military-Civil Fusion" policy also explicitly encouraged companies in China to share their technologies to upgrade the military readiness of the People's Liberation Army (Ford 2019). Other concerns included Chinese state-sponsored espionage for military, intelligence, or corporate gain, as well as its growing efforts at large-scale surveillance that threatened human rights, including with respect to repression of Uyghurs in Xinjiang.

China offers a standard menu of subsidies for the semiconductor industry common to more advanced economies, including tax credits for R&D, land concessions, and direct subsidies. For example, in 2020, the State Council (2020) announced that it would eliminate corporate income taxes of advanced semiconductor fabs for 10 years. Public companies listed on stock markets report the subsidies they have received from various levels of the Chinese government; by one tally, these reached $1.75 billion for 190 firms in 2022 (Cao 2023).

In addition, China assists its national champions by more opaque means. The China Integrated Circuit Industry Investment Fund, also known as the Big Fund, has raised tens of billions of dollars to support the local industry since its launch in 2014 (Liu and Leng 2023). OECD (2019), for example, found this has provided an especially high amount of below-market debt and equity financing to Chinese companies, with SMIC and Tsinghua Unigroup receiving government support over five years that exceeded 30 percent of their annual revenue. In addition, the Chinese government maintains talent recruitment programs targeting engineers—from Taiwan, South Korea, and elsewhere—to work for its domestic companies. Finally, the US government has accused Beijing of running broader cyber-intrusion campaigns, which threaten to steal secrets from technology companies.

China has also sought access to foreign technology by acquiring western companies, though rarely with success. In 2015, Tsinghua Unigroup attempted to buy Micron (Baker and Roumeliotis 2015). Fujian Grand Chip Investment Fund wanted, in 2016, to purchase Aixtron, a German company whose technology was used to upgrade the Patriot missile defense systems (Sheahan 2016). These and other potential deals were either discouraged or prevented by the US government. The Committee on Foreign Investment in the United States (CFIUS) has legal authority to stop company mergers or acquisitions that threaten national security. Other examples of CFIUS blocking semiconductor industry acquisitions include the Chinese investment firm Canyon Bridge Capital Partners' attempted takeover of Lattice Semiconductor Corporation, as well as the efforts by Broadcom—headquartered in Singapore at the time—which sought to acquire Qualcomm in 2018 (for more on CFIUS, see CRS 2018).[7]

7 See CRS (2018, pp. 5–7) for a discussion of the US Congressional backlash following a Japanese firm's attempted acquisition of Fairchild Semiconductor in 1987 and how the "Exon-Florio" amendment to the Defense Production Act changed the CFIUS process by which foreign investments are reviewed.

China did not take these actions lying down. In 2015, it imposed fines of nearly $1 billion against Qualcomm in an antitrust action (Dou 2015). In 2018, the Chinese government refused to greenlight Qualcomm's potential acquisition of NXP, a Dutch firm (Martina and Nellis 2018). More than half of Qualcomm's sales at the time were to companies in the Chinese market, as mentioned earlier, and at risk if the Chinese government objected to the acquisition.

Given China's economic size, its industrial policies can also disrupt global production and the allocation of resources. China's earlier efforts to dominate global production capacity—for example, in shipbuilding, steel, aluminum, and solar panels—have often created serious political-economic problems for other major economies whose firms and workers were put under unrelenting economic stress by a non-market actor.[8]

The US government has been uneasy about China's semiconductor ambitions for some time. At the end of the Obama administration, the White House (2017) published a report on semiconductors to warn that "a concerted push by China to reshape the market to favor their needs threatens the competitiveness of US industry." In principle, WTO rules can help trading partners to address some of China's actions, such as its high levels of subsidies, its treatment of foreign intellectual property, and conditioning access to the Chinese market on transferring technology to local firms. However, under the Trump administration, the United States turned away from using the WTO to tackle concerns with China (Bown and Keynes 2020; Bown 2021a) and instead deployed import tariffs (USTR 2018). Without US backing, no other country was willing to invoke the WTO to formally question China's industrial policies.

However, for all of China's efforts to become a leader in semiconductor technologies, its track record to date is decidedly mixed. In no segment of the semiconductor supply chain can Chinese firms claim leadership, although there are a few where they are not many years behind. Khan, Mann and Peterson (2021) are an early attempt that relies on revenue-based measures to assess China's role in different segments of the global semiconductor supply chain. Chinese firms are competitive in assembly, test, and package, for example, though this is a low value-added part of the supply chain. They also play some role in the design of logic chips and the production of memory chips. Yet, in the manufacturing of logic chips, China's SMIC remains several years behind TSMC. Chinese firms are also weak in the production of semiconductor equipment and the software companies creating electronic design automation tools. The main area where they are a global player is in the volume of production for the less-complex legacy chips, as further described below.

China's inability to catch up to the global technological frontier thus far is likely due to several factors. It is a latecomer. China's chip industry began in earnest only in the late 1990s, which is decades behind the leading firms from the United States, Europe, Japan, South Korea, and even Taiwan. The semiconductor industry has tended to favor incumbents, as the pace of innovation in the industry is rapid and unforgiving. Chinese semiconductor firms have struggled, in part due to their smaller commercial scale and lack of experienced personnel.

8 For details on the shipbuilding example, which mostly impacted firms in Japan and South Korea, see Barwick, Kalouptsidi and Zahur (forthcoming), as well as their paper in this symposium.

Finally, the US and other governments have, since 2019, more aggressively wielded export controls in ways that may hobble China's chip progress (described further below).

The concentration of high-end semiconductor production

The other main emerging worry for western policymakers was the extreme geographic concentration for the manufacturers of the most advanced semiconductors. Two companies—TSMC in Taiwan (92 percent) and Samsung in Korea (8 percent) dominated world production of the smallest and fastest chips, defined as semiconductor nodes below 10 nanometers (Varas et al 2021). This concentration raises various risks: geographically focused shocks due to extreme weather events, earthquakes, or public health emergencies, as well as geopolitical shocks due to risks of military confrontation with China or North Korea.

The global semiconductor shortage of 2021 stoked these fears. Especially frustrating was the unavailability of legacy chips—semiconductors that were not the most difficult to manufacture—but still essential to produce a toaster, refrigerator, microwave, washing machine, or car (Horwitz 2021; Jung-a and Olcott 2021). Indeed, in the United States and Germany, chip shortages shut down parts of the politically influential automobile industry for a time, furloughing workers (Grossman 2021; Miller and Arnold 2021).

Much of the chip shortage was clearly caused by the pandemic, not weaponization of supply chains. Indeed, some of the US chip shortage was even self-inflicted, due to the new 25 percent US import tariffs and Chinese hoarding of chips induced by the Trump administration's export controls described below (Bown 2021b). Ironically, the geographic concentration of US chipmaking facilities domestically—around Austin, Texas—also contributed to the shortage problems when a freak winter storm hit the region in February 2021 knocking down the electrical grid and throwing offline facilities belonging to Samsung, Infineon, and NXP (Fitch 2021), rather than the geographic concentration of "foreign" production. Nonetheless, the shortage experience spooked policymakers, who argued that firms' private evaluations of geographic location and supply chains did not fully recognize broader social tradeoffs.

This motivation for industrial policy is notably different from the classic arguments about how such a targeted government intervention might be able—through exclusive focus on the *benefits* of agglomeration—to improve firm-level productivity growth and possibly national economic growth.[9]

CURRENT INDUSTRIAL POLICIES FOR THE SEMICONDUCTOR SECTOR

When it comes to industrial policy for semiconductor manufacturing, the US, Japan and Europe have largely been supportive of each other's policies to date. Some modest and informal institutional arrangements have even emerged to facilitate communication across governments seeking to "coordinate" these policies—including through the US-EU Trade and Technology Council as well

9 This focus on countering the geographic concentration of production was also not unique to semiconductors but has also arisen in industrial policy for supply chains ranging from personal protective equipment (Bown 2022a) to critical minerals needed for electric vehicles (Bown 2024).

as US-Japan and EU-Japan bilateral initiatives, which have now also been extended to South Korea (Hayashi 2022; Nagao 2023; White House 2023a). That these economies have not (much) challenged each other's subsidies is likely because they have common concerns: China and the geographic concentration of production of advanced nodes in Taiwan by TSMC. Here, we discuss current industrial policies for the semiconductor industry for the United States, other major producers, and China.

The CHIPS Act of 2022 and other US policies

US industrial policy for semiconductors is evolving in a number of ways: for example, adjusting its rules for inbound foreign direct investment under CFIUS, creating notification requirements impacting outbound foreign investment (White House 2023b), and changing its use of export controls. But a major additional policy change is clearly the Creating Helpful Incentives to Produce Semiconductors (CHIPS) Act of 2022 (for details of the law, see CRS 2023).

The headline provisions of the bill involved $52 billion of subsidies and tax incentives, of which $39 billion were to be spent over five years for building, expanding, and equipping fabrication facilities in the United States. Federal expenditures were limited to up to $3 billion per project (although higher amounts could be dispersed with Presidential certification to Congress). This would only offset a portion of the construction and outfitting costs for a new fab—again, for the most advanced chips, a fab could cost $20 billion or more. For context, in 2021, TSMC alone announced it would spend $100 billion over three years to expand its global production capacity (Reuters 2021).

Implementing the CHIPS Act would first require creating administrative capacity within the US government. The Department of Commerce had to establish a new office and hire staff to solicit and evaluate private sector proposals so as to disburse its funds (Shepardson 2022, 2023). Once operational, the office created a five-step application process to allocate funding. A potential applicant for these funds would begin by submitting a "statement of interest" that would be followed by an iterative process with Department of Commerce officials, with companies offering more detailed information before any decisions were finalized (CHIPS for America 2023a). In February 2023, Commerce announced its first "Notice of Funding Opportunity" for semiconductor fabs (NIST 2023a). It would receive over 200 statements of interest over the first six weeks of the program and nearly 600 by the end of 2023 (CHIPS for America 2023b; US Department of Commerce 2024).

There are significant strings attached to CHIPS funding, however, including novel elements that sparked controversy. Funding recipients were expected to offer high quality childcare to their employees, and also to share any "windfall profits" with US taxpayers (Swanson 2023). The Commerce Department also established a rule that companies could not use CHIPS Act funding to "directly or indirectly benefit foreign countries of concern," including China (NIST 2023b, c). This rule limited what companies could do in China and was especially important to potential funding recipients like TSMC, Samsung and SK Hynix—firms whose production facilities US policymakers were attempting to attract—each of which already operated multi-billion dollar chip-making plants in China.

Four other novel elements of the CHIPS Act are worth mentioning. First, as part of the $39 billion for manufacturing incentives, $2 billion was set aside to increase US production capacity of legacy chips. These mature semiconductors are especially important for automobiles (and certain military applications); indeed, shortages of legacy chip shortages were some of the most problematic in 2021. However, these chips are not particularly profitable—as such, China's high-volume, low-profit margin, state-supported fabs make unsubsidized production noncompetitive and could end up dominating this segment of the market, resulting in a new concern involving the geographic concentration of production (Hawkins and Leonard 2023).

Second, the CHIPS Act allocated up to $500 million to subsidize the environment for assembly, test, and package facilities in countries *outside* of the United States. This provision recognized the economic difficulty of relocating certain parts of the supply chain to the United States, especially when labor costs play an important role in assembly, test, and package. In 2023, the US Department of State (2023a, b, c, d) announced that it was exploring such partnerships with Panama, Costa Rica and Vietnam—Intel already had such facilities in the latter two (Guarascio 2023; Reuters 2023a).

Third, the CHIPS Act included a 25 percent investment tax credit for capital expenses for manufacturing semiconductors and semiconductor manufacturing equipment.

Fourth, $13 billion of the $52 billion was included for R&D and for workforce development. This program may be able to draw lessons from both the SEMATECH experience as well as more recent efforts to promote R&D elsewhere, including the successful IMEC (Interuniversity Microelectronics Centre) R&D hub in Europe (Beattie 2022).

Implementing a new industrial policy program as set out by the CHIPS Act would take time. Thus, the first funding announcement was not made until December 2023. In a nod to the importance of national security motivating the legislation, the Department of Commerce (2023) awarded the first $35 million to the defense contractor BAE Systems to expand the type of chips used in F-35 fighter jets.

Nevertheless, long before any announcement of CHIPS Act grants, many of the companies expecting to receive funding under the program had already begun construction of new or expanded facilities, publicly expressing their expectation of federal funding (for example, see the press releases from TSMC 2020; Samsung 2021; Intel 2022; Micron 2022), seemingly with the support of policymakers.[10] Indeed, President Joe Biden's official visit to South Korea in May 2022 included a stop at a Samsung plant where he highlighted the company's already announced $17 billion new investment in Texas as well as the need for Congress to quickly pass and appropriate funding for the CHIPS Act to facilitate the completion of that project (White House 2022).

10 Furthermore, the broad parameters of how much the industry might be seeking under the CHIPS Act date back at least as far as March 2020 when a SIA released a commissioned study which found that the US government would need to replace an estimated $49 billion of lost revenue from purchases by Chinese device manufacturers due to decoupling (Varas and Varadarajan 2020, p. 16).

More generally, the CHIPS Act was only one—and far from the first—of numerous US policies seeking to modify the incentives that affect the decisions of these global companies regarding where to locate production. Preceding the subsidies were the Trump administration's 25 percent import tariffs, as semiconductors were one of the first products caught up in the US-China trade war that began in the summer of 2018. Over the subsequent three years, the volume of US semiconductor imports from China fell by roughly half (Bown 2022b, Fig. 9). As American chip-buyers were unable to completely shift purchases to other foreign suppliers, this, of course, contributed to the shortage of chips available in the United States in 2021.

The new US export controls of October 7, 2022 were another policy designed to affect the location of semiconductor production (BIS 2022; Schumann 2023; Bown 2022c). In the name of national security, the US planned to limit exports of the most sophisticated chips and advanced semiconductor manufacturing equipment. (Facilities in China producing older nodes would not be affected.) One year later, the United States further tightened these rules, partially in reaction to American companies like Nvidia and Intel designing chips for the Chinese market that met the letter, but apparently not the spirit, of the original US export controls (BIS 2023, Hayashi 2023). Another contribution to the tightening of the rules may have been the announcement that China's SMIC had managed to manufacture certain advanced semiconductors despite US export controls on SMIC dating back to the Trump administration (O'Keeffe and Fitch 2023).

These announcements were the latest in a deepening set of US export controls involving semiconductors and China. Under the Trump administration, in 2019, the US began to limit chip exports to China to address national security concerns related to a different sector—critical infrastructure and telecommunications. The US government worried about the Chinese company Huawei's provision of 5G telecommunications equipment, including base stations and cell towers (Bown 2020); indeed, the export controls followed a US Department of Justice (2019) indictment of Huawei for conspiracy, attempted theft of trade secrets, wire fraud, and obstruction of justice. Controls sought to limit advanced node semiconductors being made outside of China, which were an essential input into such Chinese-made 5G equipment.

The initial versions of America's export control policies met a fatal flaw. Even if many advanced chips were designed by US companies, they were physically manufactured in Taiwan or South Korea, and thus outside the jurisdiction of the first round of export controls. As an update, US officials then announced that foreign fabs could not use American-made technologies to produce chips for Huawei. Given America's dominance of semiconductor production equipment and EDA software, that would prove devastating to foreign fabs. Legally, the US government deployed the "foreign direct product rule" which gave foreign fabs a choice—if they wanted to continue to access US-made inputs (like equipment from Applied Materials, Lam Research, and KLA-Tencor), then they would have to give up selling chips to Huawei and other worrisome Chinese companies. The equipment choke point discovery was also key to the US government's later application of export controls on October 7, 2022, affecting China's semiconductor manufacturing sector itself.

Semiconductor Policies by Other Major Economies

Some elements of the US industrial policy toward semiconductors need international cooperation: for example, US export controls would be ineffective if done unilaterally, because companies in other countries would provide the goods instead. Thus, for controls on semiconductor manufacturing equipment, governments of the Netherland and Japan eventually adopted policies similar to the US controls of October 7, 2022—restricting exports of ASML and Tokyo Electron (shown in Figure 1)—in 2023 (Kelly and Uranaka 2023; Government of the Netherlands 2023).

Other countries have also acted alongside US efforts to diversify the location of production globally. Japan, for example, subsidized over $3 billion for TSMC to build a plant on the island of Kyushu (Inagaki 2023). Japan is also providing $1.3 billion to Micron to build a new factory (Nohara 2023), and it has backed Rapidus, a newly formed semiconductor manufacturer, to produce advanced-node chips in Japan, including in partnership with IBM (Kelly and Lee 2022).

Similarly, the European Union passed the European Chips Act in 2023 (Norton Rose Fulbright 2023). TSMC has received an additional €5 billion from the German government, as part of an arrangement with NXP, Infineon, and Bosch, to build a fab in Dresden (Wu and Cantrill 2023; Pasquini 2023). Germany is also providing Intel nearly €10 billion of subsidies for two plants (Heine, Mukherjee and Rinke 2023) and the Polish government has subsidized Intel's construction of a new assembly, test, and package facility in Poland (Badohal and Mukherjee 2023; Intel 2023). Despite the outbreak of war in nearby Gaza, Intel also announced it was spending $25 billion on expansion of its facilities in Israel after receiving a commitment of over $3 billion of subsidies from the Israeli government (Lu 2023.) Finally, the French government provided GlobalFoundries with €2.9 billion to build a new plant with STMicroelectronics in southeastern France (Vidalon and Kar-Gupta 2023).

Taiwan and South Korea have not remained idle as other countries seek to lure their manufacturers in the name of supply chain diversification. As the chip facilities operated in China by their multinationals (TSMC, Samsung, and SK Hynix) have dimming long-term prospects—given the US, Japanese and Dutch export controls on equipment—these leading-edge firms faced decisions of where to locate production next. To incentivize reshoring, in January 2023, Taiwan passed a law allowing its local semiconductor companies to convert 25 percent of their R&D spending into tax credits (Wang 2023). The South Korean National Assembly similarly agreed to legislation in March 2023 known as the "K-Chips Act," designed to boost the domestic semiconductor industry by expanding investment tax credits available to manufacturers like Samsung and SK Hynix (Kim 2023).

With industrial policies in play across all of these major industrialized economies, the ultimate global footprint of the industry remains highly uncertain. As one example, what happens if the hundreds of billions of industry and government dollars invested in new semiconductor facilities leads to excess global capacity? When supply of semiconductors exceeded demand in the 1980s and 1990s, the industry was known for infighting and turning to trade remedies such as antidumping and countervailing duties that sometimes ended up further limiting competition. In addition, no one is coordinating their semiconductor industrial policies with China.

Prospects for China's Semiconductor Industry

On one hand, China's technological catch-up in semiconductors is undeniably more difficult in the face of new export controls imposed by the United States, Japan, and the Netherlands. There is a plausible scenario in which Chinese firms fail to grow much from their present scale. Yet, it is also possible that the technological landscape evolves to the strengths of Chinese firms. If Chinese companies are blocked from purchasing the equipment to make high-end chips, but it turns out that there is relatively less demand for high-end chips, which go into smartphones and data servers, and more demand for low-end chips, which go into electric vehicles and consumer electronics, then the Chinese industry with its advantages in low-end chips may be able to outcompete incumbents on volume (Wang 2023b).

Furthermore, just as the US-Japan trade pact to "stabilize" the chip market in the 1980s led to opportunities for Taiwan and South Korea to enter the market, the US-led export controls begun in October 2022 may also have unintended consequences. Many Chinese companies that had previously bought from American firms now have an incentive to buy domestic chips instead (Wang 2021). Similarly, the US efforts to keep China several generations behind American technological capabilities has created undeniably higher obstacles for China's leading chipmakers; on the other hand, these firms are now being forced to work more intensively to break this bottleneck.

The future of China's policy support for its semiconductor industry is also not clear. While some press reports emphasize that Beijing is prepared to spend more than ever on semiconductor subsidies, others suggest that Beijing is pausing chip investments given their enormous cost and the country's economic problems elsewhere (compare reporting in Zhu 2022; Bloomberg News 2023). Nevertheless, many recent Chinese policies have been a retaliatory response to new foreign actions.

As one example, the Cybersecurity Administration of China announced in May 2023 that Micron had failed a security review, and barred Chinese companies involved in key infrastructure projects from buying from the US memory chipmaker (Reuters 2023b). The implied preferential access provided to Samsung and SK Hynix also works to drive a wedge between the interest of South Korean and US policymakers. In another example, following a June 2023 announcement by the Netherlands of export controls on chipmaking equipment, China retaliated with new export restrictions on gallium and germanium—materials critical to semiconductor manufacturers everywhere (Liu and Bradshaw 2023). According to the US Geological Survey (2023a, b), China was the source of 98 percent of global gallium production in 2022 and the source of 54 percent of US germanium metal imports over 2018–2021.

Finally, China blocked Intel's takeover of Tower Semiconductor, an Israel-headquartered company, by refusing to act on the proposed acquisition by August 2023 (Clark and Bradsher 2023). As Intel pivots to becoming more of a contract manufacturer—to compete with the likes of TSMC—it has attempted to acquire other foundries (Yu and Cheng 2022), and so China's denial of the Tower acquisition puts an obstacle in the way of this strategy.

RESEARCH OPPORTUNITIES IN SEMICONDUCTORS AND INDUSTRIAL POLICY

Although the modern semiconductor industry has extraordinary prominence in economics, politics, and foreign policy, it has hardly been studied by economists (for an exception, see Thurk 2022). Admittedly, empirical research into the semiconductor industry faces data constraints. There are some available from national statistical agencies, some from companies themselves in annual reports, and some from industry sources like the SIA, SEMI, the Global Semiconductor Alliance as well as consulting and market intelligence firms. Furthermore, there is also a lack of information on policy actions. Industrial policy deployed by the likes of the United States, Europe, Japan, South Korea and Taiwan is relatively transparent, though its impact must now account for not only direct subsidies but also the near simultaneous imposition of export controls, import tariffs, foreign investment screening, and sometimes antitrust actions (Evenett et al 2024). The data for Chinese policy suffers from all of those challenges and more, due to even more opaque features of its underlying economic and political system, which may require novel research approaches to "back out" the size and impact of its policies.[11]

Both the modern story of the chips sector as well as current industrial policies are substantially different than their predecessors. As the latest wave of industrial policies with regard to semiconductors starts to take effect, it will raise some familiar questions but also some new ones.[12]

For example, the modern semiconductor industry has been re-organized. Chip firms mostly did everything in-house in the 1980s. The contemporary set-up features a long and highly fragmented supply chain, with companies specializing in tasks, buying from some and selling to others, focusing on what they do best. Today's supply chains are global; thus, where firms locate geographically has also changed. Is it possible in this environment for policymakers to establish and sustain "national" champions? Are the agglomeration economies that attract policymakers—the chance of contributing to a new Silicon Valley—likely to work the same way in this new industrial structure?

Governments have been involved in semiconductor technologies since the beginning of the industry. However, their role has grown far more complex since the 1980s, when it mainly used trade policies to tackle semiconductor exports. The potential role for governments to use industrial policy to address market imperfections such as agglomeration externalities, learning by doing, and technological leadership remains relevant. But today's officials have other motives that are not driven by economic efficiency: promoting geographic

11 See the approach taken in Barwick, Kalouptsidi and Zahur (forthcoming) as applied to industrial policy for Chinese shipbuilding, as well as the accounting approach by OECD (2019) applied to semiconductors.

12 Harrison and Rodriguez-Clare (2010) provide a classic introduction to the economics of industrial policy, albeit from the historical approach of market failures in developing countries. See also Grossman (1990). For recent surveys of the economics of industrial policy, see Juhász, Lane, and Rodrik (forthcoming) and Bown (forthcoming).

diversification, blunting China's ability to make technological gains, and limiting the spread of the most advanced chips (especially those potentially involved in national security issues). Given China's enormous internal market and capable scientific community, it remains to be seen how effective efforts to limit China's semiconductor technology will be. In response to US export controls, Chinese firms are investing heavily in the production of legacy chips, which might require a further US policy response (Wang 2023b). Also, diversification of supply chains for insurance purposes is likely to be costly, including if it results in plants operating (and supply chains clustering) at smaller scale or in more places that result in fewer agglomeration externalities.

The macroeconomic climate and market structure in which industrial policy happens is also likely to affect the outcomes. During the increasingly intense competition from imported semiconductors in the 1980s, segments of the US chip sector repeatedly suffered through jarring downturns. Yet, as industrial policy really got rolling in 2021 and 2022, global semiconductor sales were the highest ever recorded—during a period of growing demand associated in part with the economic peculiarities driven by the COVID-19 pandemic (SIA 2023b). Then came another positive demand shock driven by chips needed for artificial intelligence. There is now an enormous ongoing effort from companies and governments around the world to expand semiconductor fabrication capacity, but the details of future demand for semiconductors—in total, across sectors, and across types of chips—is highly uncertain. If the current investment expansion in semiconductor manufacturing leads to overcapacity and overproduction, at least in certain product segments of the market, will future governments view taxpayer support of financial losses in those areas as a price worth paying?

Economists should seek to evaluate the extent to which industrial policy is achieving its intended outcomes, in semiconductors and other industries, the costs of doing so, all the while remaining alert to the near-certainty of its unintended consequences.

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