# U.S. EXPOSURE TO THE TAIWANESE SEMICONDUCTOR INDUSTRY

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## Abstract

In this paper, we measure U.S. exposure to the Taiwanese semiconductor industry and estimate the price and quantity effect from a hypothetical semiconductor manufacturing disruption in Taiwan. This work provides insights on the level of U.S. vulnerability in terms of relying on Taiwan-manufactured semiconductors for downstream manufacturing. Using a supply chain tracing technique with information derived from trade and industry statistics, we measure U.S. exposure by estimating Taiwanese semiconductors imported into the United States directly from Taiwan and via third countries. With a partial equilibrium (PE) segmented model of trade and production, we simulate the effect of U.S. semiconductor prices and domestic production quantities to a hypothetical Taiwan shock with a range of magnitudes. We estimate that, at the segment level, about 44.2 percent of U.S. imports of logic chips were manufactured in Taiwan, compared to 24.4 percent of memory chips and 1.0 percent of analog chips. In a hypothetical scenario of a major manufacturing disruption in Taiwan, we find that the U.S. logic chip segment would experience the largest negative impacts, which may lead to as high as a 59 percent increase in the price of logic chips that U.S. downstream producers would have to pay. Based on the current estimated capacity constraints in the United States, domestic production of logic chips would increase by as high as about 5 percent, and thus only could partially replace the reduced imports from Taiwan.



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## Introduction

Semiconductors are a vital component of many electronic devices and systems. They can be used to store and process data and perform a variety of tasks. Different types of semiconductors perform different functions. For instance, an analog chip may be used to sense an unsafe temperature spike in the motor of a car. A logic chip can act as the brain of a smart phone, controlling the device's operating system and processing data. A memory chip may be tasked with storing family photos on a personal computer. Cars, personal computers, and smartphones are a few examples of the many types of electronic products that rely on semiconductors to perform essential functions. As the world increasingly becomes more connected and digitalized, the undisrupted supply of semiconductors is critical for downstream industries as well as final consumers.

In recent years, the global supply chains (GSCs)[1] of semiconductors experienced some notable disruptions. During the COVID-19 pandemic, a surge in demand for electronic goods related to remote working, virtual learning, as well as at-home entertainment contributed to a semiconductor supply shortage in 2021. As one of the major downstream users of semiconductor, the auto industry was hit particularly hard by the shortage, resulting in billions of dollars of lost revenue.[2] Also, Russia's invasion of Ukraine in 2022 disrupted the supplies of some critical materials used in semiconductor manufacturing. Russia supplies 25–30 percent of the world supply of palladium, and Ukraine supplies 25–30 percent of the world's supply of purified neon gas, both of which are crucial for semiconductor manufacturing.[3] The invasion also triggered volatility in oil price, affecting the manufacturing and shipping costs of semiconductors. These disruptions highlight not only the importance of semiconductors in modern manufacturing, but also the vulnerabilities in semiconductor GSCs.

One primary chokepoint in the semiconductor GSCs is the outsized role played by Taiwan. While Taiwan accounts for 18 percent of global semiconductor manufacturing capacity,[4] the world almost completely relies on the economy for the production of high-end semiconductors.[5] Around 92 percent of the world's most advanced chip manufacturing capacity is located in Taiwan.[6] Any disruptions to Taiwan semiconductor manufacturing—whether caused by pandemics, natural disasters such as typhoons or earthquakes, power or water shortages, factory shutdowns, or international conflict—would potentially have large impacts on global semiconductor supply. In this paper, we attempt to measure U.S. exposure and estimate the price and quantity effect from a hypothetical semiconductor manufacturing disruption in Taiwan. This work aims to help understand the level of U.S. vulnerability in terms of relying on Taiwan-manufactured semiconductors for downstream manufacturing.

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[1] This paper distinguishes the terms of global value chains (GVCs) and global supply chains (GSCs). GVCs cover value-added activities that may be required to bring a product from a concept to end users, including six broad steps such as research and development, product design, production, logistics, marketing, and post-sale services. GSCs describe the production-related movement of tangible goods (e.g., raw materials, inputs and components, and final products). Jones et. al., "Global Value Chain Analysis: Concepts and Approaches," April 2019, 4.

[2] Burkacky, Lingemann, and Pototzky, *Coping with the Auto-Semiconductor Shortage: Strategies for Success*, May 27, 2021; U.S. International Trade Commission (USITC), *USMCA Automotive Rules of Origin: Economic Impact and Operation*, July 2023.

[3] Burkacky et al., *Semiconductor Shortage: How the Automotive Industry Can Succeed*, June 10, 2022.

[4] CRS, *Semiconductors and the Semiconductor Industry*, April 19, 2023, 9.

[5] Martin et al., *Supply Chain Interdependence and Geopolitical Vulnerability*, March 13, 2023.

[6] BCG and SIA, *Strengthening the Global Semiconductor Supply Chain in an Uncertain Era*, April 2021.

The United States is exposed to the Taiwan semiconductor industry in two ways: 1) U.S. reliance on Taiwan-manufactured semiconductors—either directly imported from Taiwan, or indirectly imported via a third country—as intermediary inputs for use in downstream manufacturing; 2) U.S. reliance on imports of final electronic products manufactured in third countries (e.g., China) that use Taiwan semiconductors as key inputs. In this paper, we focus on the former, and estimate exposure using a GSC tracing technique with information derived from trade and industry statistics. By sensitivity, we are referring to the impact of hypothetical Taiwanese manufacturing disruptions on U.S. semiconductor prices and output. We estimate sensitivity with a partial equilibrium (PE) model of trade and production that uses the estimates of exposure as inputs.

Through this exercise, we estimate that in 2021, about 44.2 percent of U.S. imports of logic chips were manufactured in Taiwan, compared to 24.4 percent of U.S. imports of memory chips and 1.0 percent of U.S. imports of analog chips from Taiwan. In a hypothetical scenario of a major manufacturing disruption in Taiwan, we find that the U.S. logic chip segment would experience the largest negative impacts. For example, a disruption in Taiwan logic chip production may lead to as high as a 59 percent increase in the U.S. price of logic chips that domestic downstream producers would have to pay. Based on the current capacity constraints, U.S. domestic production of logic chips would increase by about 5 percent, and only partially replace the reduced imports from Taiwan. The extended model results and analysis by three chip segments are described in detail in the fourth section below.

The rest of the paper is organized as follows. The first section provides some background information on the global semiconductor industry, including the description of three major segments of semiconductors, global semiconductor manufacturing capacities and utilizations, as well as the recent development of global semiconductor value chains. The second section describes the semiconductor industry in the United States. The third section illustrates the GSC tracing technique used in this paper and provides the estimation of U.S. exposure to the Taiwan semiconductor industry—the dollar value and share of U.S. semiconductor imports that were originally manufactured in Taiwan. The fourth section presents a PE modeling approach to estimate the sensitivity of U.S. prices and quantities to a hypothetical Taiwan manufacturing disruption. It includes a detailed description of the equations, data and parameter inputs, and model results. Finally, we conclude the paper with thoughts about data improvement and areas for further research.

# I. Global Semiconductor Industry

Semiconductors are essential to the operation of countless electronic devices that have become integral to modern society. From the microprocessors in smartphones and computers to the diodes in televisions and microcontrollers in automotive systems, semiconductors are the building blocks of the digital age. They are also critical to emerging technologies, such as artificial intelligence, robotics, and quantum computing.

The term "semiconductor" refers to a broad range of microelectronic components and devices that perform a wide range of functions in electronic circuits and systems.[7] These products are manufactured using semiconductive materials, such as silicon. Semiconductor products include integrated circuits (ICs),

[7] Lotze, *From Silicon to Donkey Kong*, March 2023, 5.

discrete devices, optoelectronics, and sensors. Each product segment requires specific design and manufacturing processes.[8]

ICs, also known as "chips," are the focus of this paper. They are tiny electronic circuits containing thousands or millions of interconnected electronic components, such as transistors, diodes, resistors, and capacitors, all fabricated onto a single semiconductor wafer or substrate. They can process, store, sense, and move data or signals, playing a pivotal role in the functioning of electronic devices in terms of memory, sensors, communications, and power lines.[9]

ICs can be further broken down into three main segments: logic chips, memory chips, and analog chips.

- **Logic chips.** Logic chips are ICs that process data, execute software, and complete tasks. They are often described as the "brains" of electronic devices. Two notable forms of logic chips are microprocessors (MPUs) and microcontrollers (MCUs). Central processing units (CPUs) are the primary MPU used in computer or computer-based device and are responsible for interpreting most of a computer's commands. Graphics processing units (GPUs) are another type of MPU specializing in graphics rendering, but also have applications in artificial intelligence and deep learning. MCUs are similar to MPUs in that they execute logic functions, but differ in that they contain other components, such as embedded internal memory and are designed for more limited tasks. Logic chips are primarily used in smartphones, high-performance computing, Internet of Things devices, and the automotive sector.[10]
- **Memory chips.** Memory chips are used to store data. Primary examples of memory chips include dynamic random-access memory (DRAM) as well as a Not And (NAND) flash memory. DRAM holds short-term data and requires the device to be powered on, while NAND flash memory provides long-term storage even after a device is powered off.[11] Memory chips are used in mobile phones, data centers, and personal computing devices.[12]
- **Analog chips.** Analog chips use analog signals, as opposed to digital ones. They function by representing a continuous real-world signal (in the form of a wave), with a proportional electronic voltage or current. Analog chips perform a wide range of functions, such as power management, audio and video conversion, audio amplification, and can include certain sensors.[13] For example, analog chips are used in electric vehicles for power management, mobile phones (for example, 5G, Bluetooth, wireless connectivity), as well as military detection and surveillance equipment (for example, radar, sonar, infrared imaging).[14]

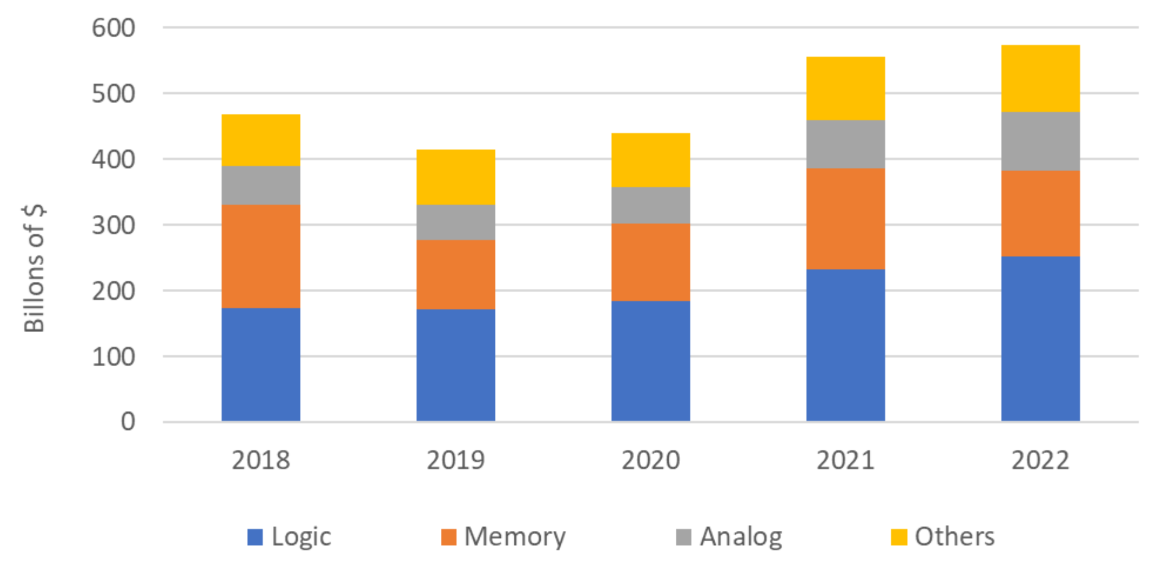
Global semiconductor sales reached all time high first at $556 billion in 2021, and then $574 billion in 2022. The sales value of logic chips surpassed memory chips and has maintained the lead since 2019. These two product segments accounted for about 70 percent of global semiconductor sales (figure 1). The value of the global semiconductor market is projected to nearly double, surpassing $1 trillion by

[8] CRS, *Semiconductors and the Semiconductor Industry*, April 19, 2023.
[9] SIA, "Semiconductors Are the Brains of Modern Electronics," accessed September 15, 2023.
[10] CRS, *Semiconductors and the Semiconductor Industry*, April 19, 2023, 3.
[11] CRS, *Semiconductors and the Semiconductor Industry*, April 19, 2023, 4.
[12] ASML, "Learn the Microchip Basics," accessed October 11, 2023.
[13] Lotze, *From Silicon to Donkey Kong*, March 2023, 14–15.
[14] CRS, April 19, 2023, Semiconductors and the Semiconductor Industry, p. 6.

2030. Computing and data storage, wireless communication, and automotive electronics are expected to lead the industry growth in the next decade.[15]

China—the world's largest manufacturing nation in terms of output—is the largest downstream user of semiconductors, accounting for 32 percent of global semiconductor sales in 2022.[16] Chinese manufacturers incorporate these semiconductors into a range of electronic products that are either consumed domestically or exported globally. The United States and China were the top final consumers of semiconductors at 25 percent and 24 percent, respectively, followed by the European Union (EU) at 20 percent.[17]

**Figure 1** Global semiconductor sales by major product segment, billions of dollars, 2018–22



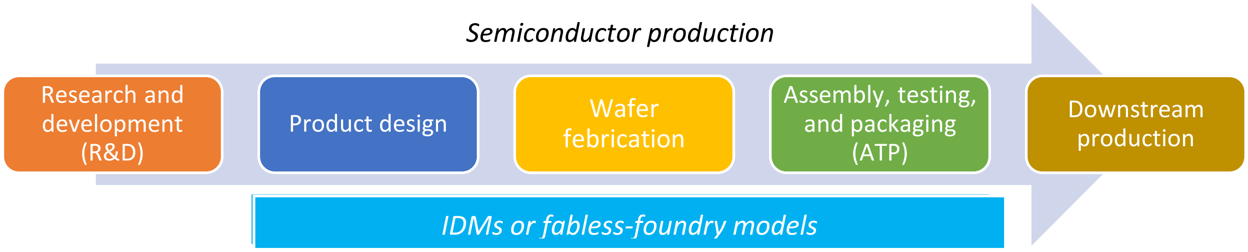

Source: SIA, *2019 Factbook*, May 2019; *2020 Factbook*, April 2020; *2021 Factbook*, May 2021; *2022 Factbook*, May 2022; and *2023 Factbook*, May 2023.

## Global Semiconductor Value Chains Development

In general, semiconductor value chains consist of five major stages: research and development (R&D); product design; chip manufacturing, also referred to as wafer fabrication; assembly, testing, and packaging (ATP); and downstream production (figure 2). Wafer fabrication is sometimes referred to as "front-end manufacturing," while ATP is referred to as "back-end manufacturing."

[15] MCK, "Semiconductors Supply Shortage and Its Implications," November 10, 2022.
[16] Statista, "Semiconductor Market Size by Region 2022," March 1, 2023.
[17] Final consumers refer to the location of end users that purchase electronic devices with incorporated semiconductors. BCG and SIA, *Strengthening the Global Semiconductor Supply Chain in an Uncertain Era*, April 2021, 11; Jones and Lotze, ""Recent Development in Global Semiconductor Industry," November 2023.

**Figure 2** Five major stages of semiconductor value chains
R&D= research and development; IDM= integrated device manufacturers.




Source: Authors adapted from Jones et al., "The Rising Role of Re-Exporting Hubs in Global Value Chains," April 2020.

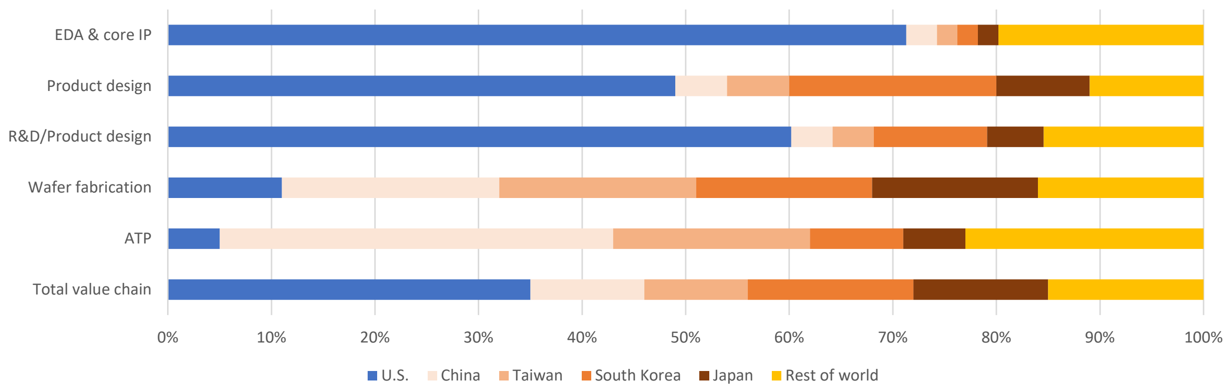
In the 1990s, semiconductor value chains were usually vertically integrated within a company and mainly concentrated in two countries—the United States and Japan. Since then, semiconductor value chains have become increasingly fragmented across more than a dozen countries.[18] In 2021, U.S. chip companies still capture the largest share of value created in the global semiconductor industry, though they focus more on the upstream activities such as R&D as well as product design. Although a few U.S. companies still operate as integrated device manufacturers (IDMs) and retain in-house manufacturing/fabrication facilities (also referred to as "fabs"), some of them have relocated fabs to other countries where the production costs are lower. Meanwhile, quite a few U.S. companies adopted the fabless model, focusing on product design and outsourcing manufacturing activities to foundries (contract semiconductor manufacturers) located in East Asia. As a result of such global value chain development, four Asian economies—Taiwan, South Korea, China, and Japan—registered over 70 percent of value created from global semiconductor manufacturing activities including wafer fabrication and ATP (figure 3).[19]

The process of manufacturing chips is called wafer fabrication and involves hundreds of sequential processing steps to create electrical or photonic circuits on semiconductor wafers.[20] The manufactured chips need to be assembled, tested, and packaged before incorporation into final electronic products by downstream manufacturers. The assembly, testing, and packaging of chips are labor intensive and often outsourced to third-party semiconductor packaging and test services (OSAT) located in low-labor cost countries. Several Asian countries, including Vietnam, Malaysia, Thailand, and the Philippines, have increasingly provided ATP services due to their proximity to the big four Asian semiconductor producers as well as their relatively low labor costs.[21]

[18] Jones et al., "The Rising Role of Re-Exporting Hubs in Global Value Chains," April 2020.
[19] SIA, *2022 State of the U.S. Semiconductor Industry*, October 2022.
[20] Academic Accelerator, "Wafer Fabrication," accessed September 19, 2023.
[21] Jones et al., "The Rising Role of Re-Exporting Hubs in Global Value Chains," April 2020.

**Figure 3** Share of global semiconductor value chains by activity, 2021

EDA = electronic design automation; IP = intellectual property; R&D = research and development; ATP = assembly, testing, and packaging.




Source: Authors compiled and adapted based on SIA, *2022 State of the U.S. Semiconductor Industry*, October 2022.

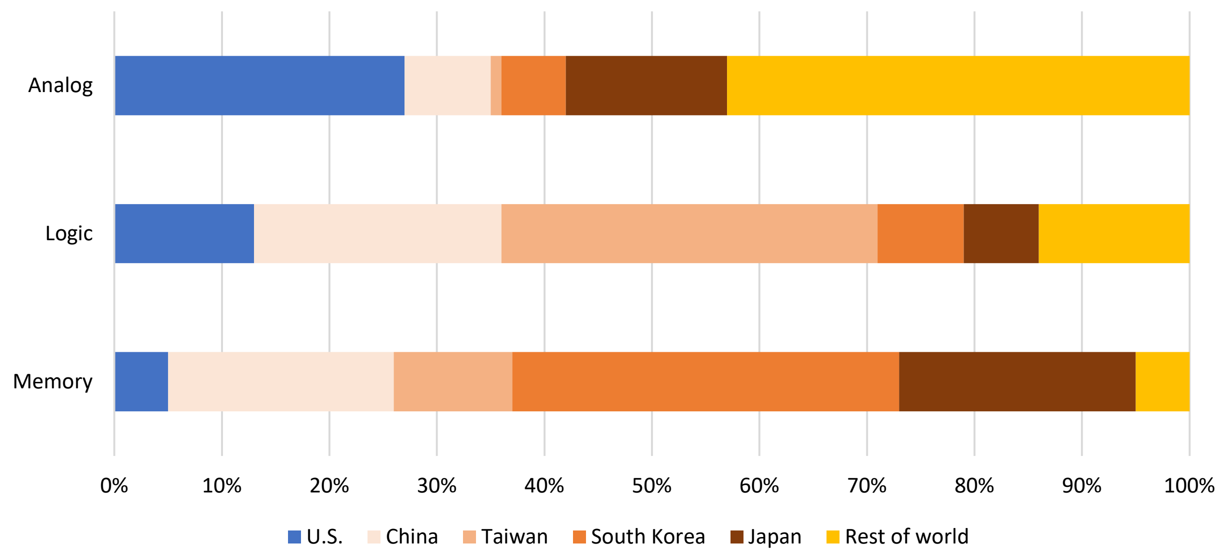
## Manufacturing Capacity and Utilization

Different sources provide slightly different estimates on semiconductor manufacturing capacity by region. According to Knometa Research, at the end of 2021, global installed fabrication capacity was 21.6 million 200mm-equivalent wafers per month. About 75 percent of wafer fabrication capacity was in four Asian economies: South Korea, Taiwan, China, and Japan.[22] Five leading companies owned 57 percent of global installed capacity: Samsung (South Korea), 19 percent; TSMC (Taiwan), 13 percent; Micro (U.S.), 10 percent; SK Hynix (South Korea), 9 percent; and Kioxia/WD (Japan), 6 percent.[23] American companies owned about 21 percent of global installed capacity, though over half was located overseas.[24]

According to a recent Congressional Research Service (CRS) report, in 2020, South Korea led the world in memory chips manufacturing with 36 percent of wafer fabrication capacity, followed by Japan (22 percent), China (21 percent), and Taiwan (11 percent). Taiwan led the world in logic chip manufacturing with 35 percent of wafer fabrication capacity, followed by China (23 percent), and the United States (13 percent). The United States and Japan had the largest fabrication capacity for analog chips, accounting for 27 percent and 15 percent, respectively (figure 4).[25]

[22] Knometa Research, "China's Share of Global Wafer Capacity Continues to Climb," February 10, 2022.
[23] Knometa Research, "Top Five Leaders Continue Expanding Share of Global IC Fab Capacity," April 7, 2022.
[24] Knometa Research, "More Than Half of American-Owned IC Fab Capacity Exists Overseas," January 31, 2023.
[25] CRS, *Semiconductors and the Semiconductor Industry*, April 19, 2023, 9.

**Figure 4** Global IC wafer fabrication capacity by type of chips and region, 2020



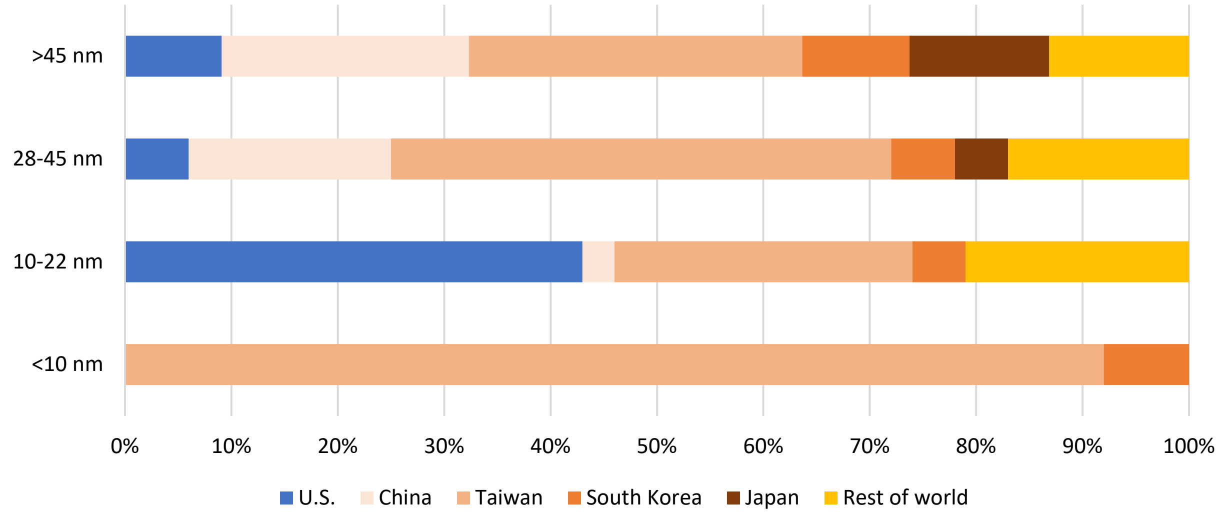

Source: SEMI, World Fab Forecast, November 2020; CRS, *Semiconductors and the Semiconductor Industry*, April 19, 2023, 9.

Logic chips can vary in complexity and are typically denoted by their "node" size. The term "technology node," indicated in nanometer (nm), refers to a specific manufacturing process and design rules that govern the dimensions, transistor characteristics, and performance capabilities of the chips. For example, 22nm, 16nm, 14nm, and 10nm are technology nodes. Generally, the smaller the technology node is, the faster, more power-efficient, and more technologically advanced the chips are.[26] According to a joint report produced by Boston Consultant Group (BCG) and the Semiconductor Industry Association (SIA), in 2019, Taiwan dominated the advanced logic chip manufacturing—technology node under 10nm—with a 92 percent of fabrication capacity, while South Korea accounted for the remaining 8 percent in this logic chip segment (figure 5).[27]

[26] Larger technology nodes, which use older technology, are often referred to as "legacy" chips. Chips built on legacy nodes, such as certain microcontrollers, are still significant inputs used by the automotive and medical devices industries. Chips with advanced node sizes are critical components for smartphones and laptops and have applications in artificial intelligence and cloud computing. WikiChip, "Technology Node," accessed September 14, 2023; Department of Commerce, "Results from Semiconductor Supply Chain Request for Information," January 25, 2022; Arias, Meng, "Understanding CHIPS, Part One: The Semiconductor Manufacturing Challenge," March 20, 2023.

[27] BCG and SIA, *Strengthening the Global Semiconductor Supply Chain in an Uncertain Era*, April 2021, 35.

**Figure 5** Global logic chip wafer fabrication capacity by technology node and region, 2019
nm = nanometer.

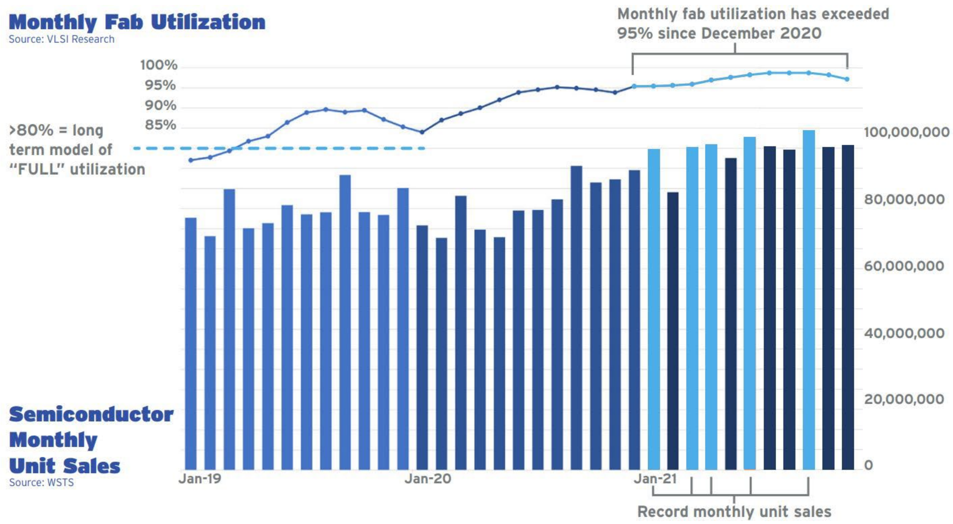



Source: BCG and SIA, *Strengthening the Global Semiconductor Supply Chain in an Uncertain Era*, April 2021, 35.

Fabrication capacity utilization rate is a term that refers to the percentage of total available manufacturing capacity that is being used at a given time.[28] This measure helps to assess how well a given industry is utilizing its full production potential vis-à-vis prevailing supply and demand trends, and how much spare production capacity is available at a given point of time for ramping up manufacturing without the cost of additional investment into expanding production. Globally, the long-term "full" manufacturing capacity utilization rate for semiconductor is considered to be about 80 percent.[29] Fabs are generally unable to sustain rates above this for extended periods.[30] However, as the global demand for semiconductors reached an all-time high during the COVID-19 pandemic, semiconductor manufacturers ramped up fab utilization rates well above this "full" rate. Throughout 2021, the average monthly fab utilization rates exceeded 95 percent (figure 6).[31] These high levels of capacity utilization rate suggest there is very limited short-term ability for producers to expand the existing production or switch the production between different product segments.

[28] SIA, "Chipmakers Are Ramping Up Production," February 26, 2021.
[29] SIA, "Increasing Chip Production," February 9, 2022. Most semiconductor manufacturing facilities operate at around 80 percent utilization and modify this capacity to accommodate fluctuations in demand.
[30] SIA, *2022 State of the U.S. Semiconductor Industry*, 19, 14.
[31] SIA, "Increasing Chip Production," February 9, 2022.

**Figure 6.** Global semiconductor manufacturing capacity utilization rate, January 2019–November 2021




Source: SIA, "Increasing Chip Production," February 9, 2022. Note: the light blue columns mark the new monthly record high.

Increasing utilization rates in existing fabs can only be a short-term solution. Over the long run, upgrading the existing fabrication facilities and building new fabs to increase total global fab capacity is needed in order to meet the long-term projected demand growth for chips. The process of bringing a new fab into operation costs billions of dollars, and typically takes two to five years from the start of construction to the launch of production, depending on the complexity of manufactured semiconductor products.[32]

## II. U.S. Semiconductor Industry

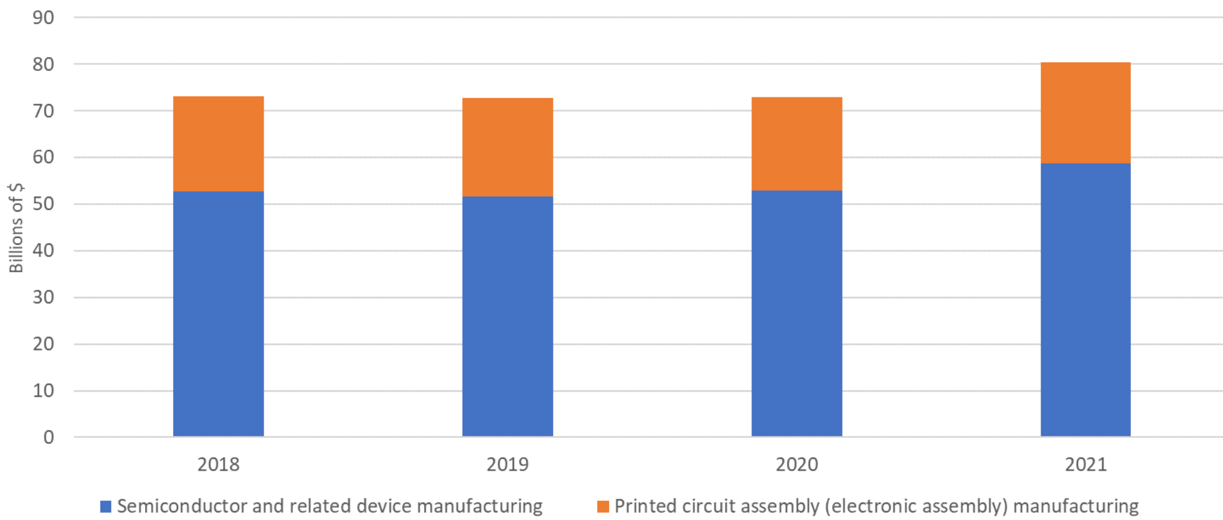
Semiconductors play a vital role in the U.S. economy. According to SIA, in 2021, via all channels (direct, indirect, and induced), the U.S. semiconductor industry contributed about $276.9 billion to the U.S. economy (about 1.2 percent of U.S. gross domestic product—GDP, and 4.3 percent of U.S. manufacturing GDP in 2021) and supported 1.84 million jobs.[33] Semiconductors were the United States' fourth largest exported good behind refined petroleum products, aircrafts, and crude oil.[34]

As mentioned previously, due to outsourcing and re-location, the U.S. share of global semiconductor manufacturing capacity by geographic location has declined to approximately 10–13 percent in recent years. Over 2018–20, the average annual value of U.S. shipment from domestic semiconductor-related manufacturing was about $73.0 billion. Given the higher demand for electronics as the country shifted to the virtual working during the pandemic, in 2021, U.S. semiconductor shipments increased by 10

[32] CRS, *Semiconductors and the Semiconductor Industry*, April 19, 2023.
[33] SIA, *2022 State of the U.S. Semiconductor Industry*, October 2022, 22, 25.
[34] SIA, *2022 State of the U.S. Semiconductor Industry*, October 2022, 22.

percent to $80.4 billion (figure 7),[35] and the U.S. capacity utilization rate rose to as high as 88.1 percent in May 2021.[36]

**Figure 7** Value of U.S. shipment from semiconductor-related manufacturing, 2018–21




Source: U.S. Census, "Annual Survey of Manufacturers," accessed September 25, 2023.

Transport equipment, primarily aircrafts and automobiles, is the top downstream industry user of semiconductors in the United States, followed by computer and electronics products, machinery, professional, scientific and technical services (primarily computer systems design and related services), and telecommunications.[37]

The global semiconductor supply chain disruptions and chip shortage in recent years impacted both U.S. consumers and producers.[38] The U.S. automotive industry, in particular, suffered periodic production stoppages and reduction due to the shortages of automotive microcontrollers, which are used throughout modern vehicles from the engine and transmission to the airbags and doors.[39] Such experience highlighted both the existing production capacity constraints faced by the global semiconductor industry, as well as the U.S. reliance on imported semiconductors from Taiwan and other major producers in East Asia.

Recognizing the vulnerabilities in U.S. dependence on imported semiconductors and the lack of critical domestic semiconductor production capabilities, in July 2022, Congress enacted the CHIPS and Science Act (CHIPS), which President Biden signed into law in August 2022. The CHIPS Act injects $52.7 billion over

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[35] U.S. Census, "Annual Survey of Manufacturers," accessed September 25, 2023.
[36] Federal Reserve, "Capacity Utilization," accessed October 2, 2023. Note: The utilization rate is based on NAICS 3344, "Semiconductor and other electronic component manufacturing."
[37] BEA, "The Use Table (Supply-Use Framework), 2012," accessed September 22, 2023.
[38] BCG and SIA, *Strengthening the Global Semiconductor Supply Chain in an Uncertain Era*, April 2021, 11.
[39] SIA, *2023 Factbook*, May 5, 2023, 8; U.S. International Trade Commission (USITC), *USMCA Automotive Rules of Origin: Economic Impact and Operation*, July 2023, 40; Bethmann et. al, "Challenges Facing Selected Industries and Related Global Supply Chains During the Ongoing COVID-19 Pandemic," February 2022; Leonard, "Why the Automotive Supply Chain Is in a Semiconductor Jam," February 23, 2021.

FY2022–27 to expand semiconductor manufacturing capacity in the United States and supports federal R&D activities, while bolstering U.S. semiconductor capabilities for national defense, workforce development, and international cooperation.[40] Specifically, the law is expected to allocate$39 billion for manufacturing incentives (including $2 billion for the legacy chips used in automobiles and defense systems), $13.2 billion for R&D and workforce development, and $500 million for international information communications technology security and semiconductor supply chain activities. Further, the law provides a 25 percent investment tax credit for capital expenses for manufacturing of semiconductors and related equipment.[41] Since the introduction of the CHIPS Act in 2020, various companies announced dozens of projects across 20 states, amounting to over $200 billion of investment, while the number of new commitments is expected to grow as the implementation of the law unfolds.[42]

## III. U.S. Exposure to Taiwan Semiconductor Industry

In the past decades, Taiwan—a small island of 26,197 square kilometers (slightly larger than the state of Maryland) and separated from China by the Taiwan Strait—has emerged as one of the leaders in the global semiconductor industry. In 2021, the Taiwan semiconductor industry generated $137 billion in output, approximating to 24.6 percent of global semiconductor sales ($556 billion) of the year.[43] Taiwan has achieved the prominent role primarily through its foundry services. Four Taiwanese companies, including Taiwan Semiconductor Manufacturing Company (TSMC)—the world's largest foundry, were ranked among the world's top ten foundries, together accounting for 68.7 percent of global foundry services revenue in the first quarter of 2023.[44]

It is difficult to measure U.S. exposure to Taiwan semiconductor industry for a number of reasons. First, due to the configuration of semiconductor supply chains and the associated trade flows within the global production network, it is hard to directly trace the movement of semiconductors through different stages of production (figure 2). Chips can be initially manufactured in Taiwan, then sent to a third country for assembly, testing, and packaging, before being shipped to the United States for downstream production. Therefore, the sources of U.S. semiconductor imports in trade statistics likely reflect the last locations where ATP services are performed instead of the original manufacturing sites.

Secondly, economies can be specialized in different segments of the semiconductor market. For instance, Taiwan has bigger manufacturing capacity for logic chips, while South Korea has bigger manufacturing capacity for memory chips, and the United States for analog chips. Thus, it is necessary to examine U.S. exposure to Taiwan semiconductor industry by chip segment in addition to aggregate-level analysis. However, chip segments do not map perfectly to the Harmonized Tariff Schedule (HTS) classifications, making it infeasible to break down U.S. imports by segment based on merchandise trade statistics alone.

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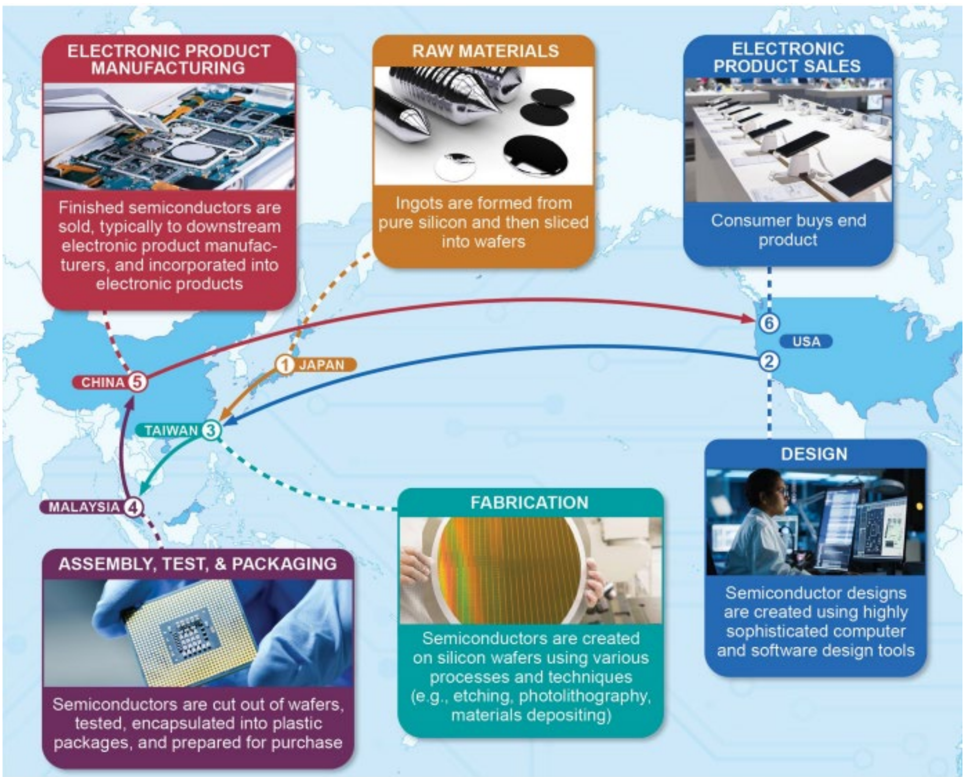
[40] Division A of P.L.117-167 – "The CHIPS Act of 2022", widely known as the "CHIPS and Science Act." CRS, *Semiconductors and the CHIPS Act*, September 28, 2023, 1; White House, "FACT SHEET: CHIPS and Science Act Will Lower Costs," August 9, 2022.
[41] White House, "FACT SHEET: CHIPS and Science Act Will Lower Costs," August 9, 2022.
[42] SIA, *2023 State of the U.S. Semiconductor Industry*, 2023, 4.
[43] TSIA, "Newsletter No. 105," July 2023., May 2021.
[44] TrendForce, "Top 10 Foundries Report Nearly 20% QoQ Revenue Decline in 1Q23," June 12, 2023.

Thirdly, the United States is exposed to the Taiwan semiconductor industry in two ways: 1) U.S. reliance on Taiwan-manufactured semiconductors—either directly imported from Taiwan, or indirectly imported via a third country—as intermediary inputs for use in downstream manufacturing; 2) U.S. reliance on imports of final electronic products manufactured in third countries (e.g., China) that use Taiwan semiconductors as key inputs (figure 8).[45] This paper focuses on the former, estimating U.S. exposure and vulnerability to Taiwan's semiconductor industry at an aggregate level and by chip segment. The total U.S. exposure to the Taiwan semiconductor industry would be likely much larger than the findings in this paper.

**Figure 8** Illustration of a global semiconductor process




Source: Congressional Research Service, *Semiconductors: U.S. Industry, Global Competition and Federal Policy*, R46581 (Oct. 26, 2020) which was adapted from information provided by the Semiconductor Industry Association (information), GAO analysis (presentation), and Gorodenkoff/I'm Thongchai/frog/22091967/bodnarphoto/stock.adobe.com (photos) | GAO-22-105923

Source: GAO, *Semiconductor Supply Chain*, July 2022, 5.

In 2021, the United States imported about $62.1 billion of semiconductors (table 1).[46] Among the eight largest import sources, South Korea, Taiwan, China, and Japan are the top semiconductor manufacturers. China and Taiwan are also the top ATP providers with over 50 percent of ATP facilities in the world.[47] Comparatively, Japan and South Korea also provide some ATP services, though in a smaller scale. Malaysia, Vietnam, the Philippines, and Thailand are known to be specialized in providing ATP services with

[45] To measure exposure in the latter, it requires the use of trade in value added statistics, which are not available at such a granular level.

[46] USITC and USDOC, Dataweb, accessed June 21, 2023. Including HTS 84.73.30.11 "Printed circuit assemblies" and HTS 8542 "Electronic integrated circuits."

[47] CSIS, "Mapping the Semiconductor Supply Chain," May 30, 2023.

insignificant wafer fabrication capacity if any. Therefore, U.S. imports of semiconductors from South Korea, Taiwan, China, and Japan could be a mixture of chips produced domestically, and chips produced abroad which the ATP services are performed upon. Meanwhile, U.S. imports of semiconductors from Malaysia, Vietnam, the Philippines, and Thailand are mostly likely produced in somewhere else.

Table 1 U.S. imports for consumption of semiconductors, 2021
Millions of dollars and percentage.

| Economy | U.S. imports for consumption | Share |
|---|---|---|
| Malaysia | 19,213 | 31.0 |
| Taiwan | 11,973 | 19.3 |
| South Korea | 10,099 | 16.3 |
| Vietnam | 5,216 | 8.4 |
| China | 3,092 | 5.0 |
| Philippines | 2,678 | 4.3 |
| Thailand | 1,491 | 2.4 |
| Japan | 996 | 1.6 |
| Rest of world | 7,290 | 11.7 |
| Total | 62,050 | 100.0 |

Source: USITC and USDOC, Dataweb, accessed June 21, 2023.
Note: Including HTS 84.73.30.11 “Printed circuit assemblies” and HTS 8542 “Electronic integrated circuits.”

To estimate U.S. exposure to Taiwan semiconductor industry, we trace U.S. semiconductor imports back to manufacturers with a methodology originally developed for a USITC study, *Seafood Obtained via Illegal, Unreported, and Unregulated Fishing: U.S. Imports and Economic Impact on U.S. Commercial Fisheries*. The methodology uses trade and production data to estimate the make-up of each partner country’s exportable supply—the total supply of products that could be exported to the United States. Exportable supply consists of that partner country’s own production plus their imports from other countries.[48] We modified this approach to incorporate the unique characteristics of the global semiconductor supply chains.

Since Taiwan is more prominent in manufacturing logic chips than memory or analog chips, there is a need to estimate U.S. exposure to Taiwan semiconductor industry by segment. The current Harmonized Tariff Schedule (HTS) assigns 854232 for memory chips; however, it does not assign different codes for logic and analog chips. Instead, both logic and analog chips can be imported under 84733011, 854231, and 854239. To address this issue, we first use industry data such as global sales and wafer fabrication capacity by segment to estimate each country’s domestic production in value term. For instance, in 2021, global sales of logic chips (including MPU and PCU) were $232.2 billion and global sales of analog chips were $74.1 billion. Taiwan has 35 percent of global manufacturing capacity in logic chips and only 1 percent in analog chips. Therefore, we estimate Taiwan’s logic chip production in 2021 was about $81.3 billion and analog chip production was about $0.7 billion. The ratio of Taiwan logic and analog chip production is 99:1. We then apply this ratio to U.S. as well as other countries’ imports from Taiwan to derive the respective logic and analog imports.

[48] USITC, *Seafood Obtained via Illegal, Unreported, and Unregulated Fishing*, February 2021, Appendix F.

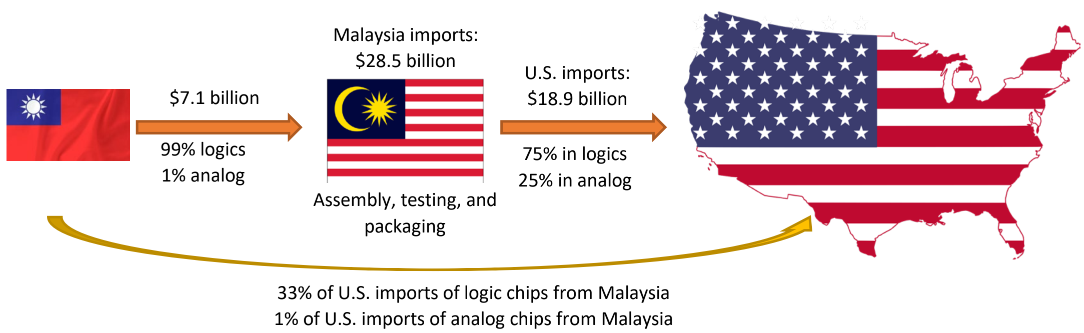
The supply chain tracing methodology is illustrated with the examples of Malaysia and Taiwan, two economies that perform different roles in global semiconductor supply chains. Malaysia is a major hub for the final steps of the chipmaking processes, primarily performing the back-end manufacturing—providing 13 percent of global ATP services, mostly on chips manufactured outside of Malaysia, such as the United States or South Korea. It is estimated that about 7 percent of global semiconductor trade passes through Malaysia.[49] Taiwan primarily offers foundry services, or performs the front-end manufacturing such as wafer fabrication, though it also provides ATP services to chips produced inside and outside of Taiwan.

Example 1: Tracing U.S. logic and analog chip imports from Malaysia

In 2021, the United States imported $18.9 billion, or 32.1 percent of the logic and analog chips from Malaysia. In the same year, Malaysia imported about $28.5 billion of the same product group, primarily from other Asian producers such as Taiwan, China, South Korea, as well as the United States. Since we do not have data on Malaysia's wafer fabrication capacity, and we also know that if Malaysia has any fabrication capacity, it would be miniscule. Therefore, in this exercise, we treat Malaysia's domestic production of logics and analog chips as zero. Using Malaysia's import data as well as its top sourcing economies' production ratio between logic and analog chips as discussed above, we estimate the ratio of logic and analog chips in Malaysia's imports, as well as sourcing economies' share in each segment. We then apply these ratios to U.S. imports from Malaysia and reattribute shares to the sourcing economies.

In the illustration below (figure 9), it shows in 2021, Malaysia imported $7.1 billion of logic and analog chips from Taiwan. Based on the Taiwan production ratio between logic and analog chips (99:1), we derive that of Malaysia imports from Taiwan, about $7.07 billion were logic chips and $0.06 billion were analog chips. After we apply similar approaches to other major sourcing economies, we estimate about 75 percent of Malaysia imports were logic chips and 25 percent were analog chips, and Taiwan accounted for about 33 percent of Malaysia imports of logic chips and only 1 percent of Malaysia imports of analog chips. We apply these ratios to U.S. imports from Malaysia, and then redistribute the share from Malaysia to Taiwan.

**Figure 9** Estimating U.S. imports of logic and analog chips from Taiwan through Malaysia, 2021



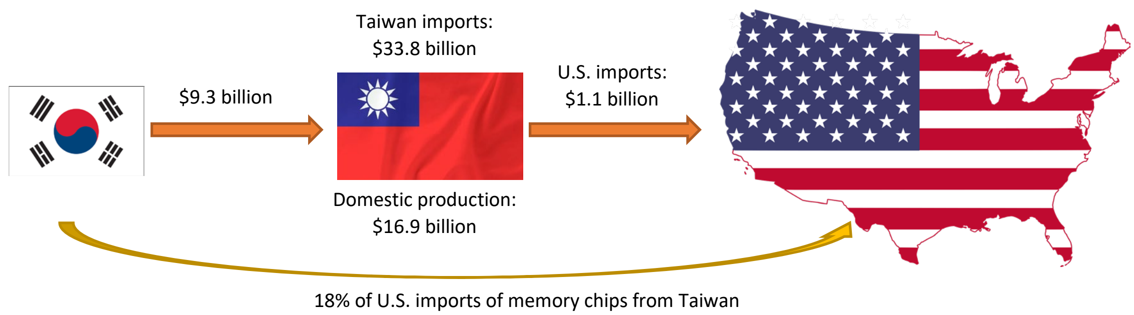

Source: Authors' calculations and illustration.

[49] Lee, "Malaysian Chip Makers Still Struggling to Meet Demand, Association Says," August 26, 2021.

Example 2: Tracing U.S. imports of memory chips from Taiwan

In 2021, U.S. imported $2.2 billion of memory chips (HTS 854232). About half of U.S. imports came from Taiwan ($1.1 billion). In the same year, Taiwan imported $33.8 billion of memory chips, of which $9.3 billion came from South Korea. Using Taiwan's share in global memory chip wafer fabrication capacity as well as global sales of memory chips, we estimate Taiwan domestic production of memory chips was about $16.9 billion in 2021. Based on Taiwan import and domestic production data, we then estimate that South Korea accounted for about 18.3 percent of U.S. imports of memory chips from Taiwan (figure 10). We then redistribute the share from Taiwan to South Korea.

**Figure 10** Estimating U.S. imports of memory chips from South Korea through Taiwan, 2021




Source: Authors' calculations andillustration.

After performing such tracing and redistribution exercise across the top supplying economies for memory, logic and analog chips, we derive the following shares for U.S. imports (table 2).

**Table 2** U.S. imports of semiconductor products by major source economy and by type of chips, percentage, 2021

| | U.S. import data | Adj. estimate for memory chip | Adj. estimate for logic chip | Adj. estimate for analog chip |
|---|---|---|---|---|
| Malaysia | 31.0 | 0.0 | 0.0 | 0.0 |
| Taiwan | 19.3 | 24.4 | 44.2 | 1.0 |
| S. Korea | 16.3 | 30.4 | 15.4 | 12.0 |
| Vietnam | 8.4 | 0.0 | 0.0 | 0.0 |
| China | 5.0 | 18.9 | 16.9 | 6.4 |
| Philippines | 4.3 | 0.0 | 0.0 | 0.0 |
| Thailand | 2.1 | 0.0 | 0.0 | 0.0 |
| Japan | 1.6 | 12.8 | 4.0 | 10.9 |
| Rest of world | 11.7 | 13.5 | 19.4 | 69.7 |
| @Total | 100.0 | 100.0 | 100.0 | 100.0 |

Source: Authors calculated and estimated based on USITC/USDOC, Dataweb, accessed June 21, 2023.

# IV. Modeling the Sensitivity of U.S. Prices and Output to Manufacturing Disruptions in Taiwan

A hypothetical manufacturing disruption that reduces the supply of Taiwan-manufactured semiconductors would affect U.S. downstream users of semiconductors, as well as U.S. domestic producers of semiconductors who compete directly with imports from Taiwan. The impact on U.S. downstream users is more straightforward: a reduction in supply of Taiwan-manufactured chips would increase the average price that they pay, and thus reduce the quantity they demand. Comparatively, the impact on U.S. domestic producers is not as clear, depending on several factors, including to the extent that they have the spare manufacturing capacity, and/or they can bring on new manufacturing capacity quickly. Domestic producers may potentially benefit from the substitution effect, which downstream users shift their purchase from Taiwan-manufactured chips to U.S.-produced varieties. They may also be negatively impacted by reduced demand from downstream industries—downstream industry users may respond to the loss of the supply of Taiwan-manufactured semiconductors and the accompanied price hikes with production reduction, thus reduce demand for U.S. produced chips. The PE model simulation and associated analysis presented below attempt to measure the impacts on U.S. prices and quantities from a hypothetical manufacturing shock in Taiwan, based on U.S. exposure estimated in the section above. The purpose of the modeling exercise is to understand the sensitivity of the U.S. market to Taiwan semiconductor manufacturing.

## Approach

We employ a PE modeling framework to estimate the sensitivity of the U.S. domestic semiconductor market to a hypothetical manufacturing disruption in Taiwan. The goal of the analysis is to show the sensitivity of the U.S. market in terms of semiconductor prices and domestic production, which in turn affects U.S. downstream industries that use semiconductors as key inputs. The model is a partial equilibrium representation of the United States market for semiconductors. It is designed to estimate the impact of an exogenous quantity shock in U.S. imports, corresponding to a reduction in semiconductors manufactured in Taiwan, on U.S. production, trade, and prices. The model equations use constant elasticity of substitution (CES) demand functional forms, where varieties of semiconductors are differentiated by where they were manufactured, not the last point of departure before importation into the United States. Consumers in the model are downstream producers who "consume" semiconductors as inputs in their manufacturing processes.[50] Equation (1) is the U.S. semiconductor price index, where $p_i$ is the price of the variety manufactured in country *i*, $b_i$ is a demand asymmetry parameter, and σ is the constant elasticity of substitution across varieties.

$$P = \left( \sum_i \left( b_i \, p_i^{1-\sigma} \right) \right)^{\frac{1}{1-\sigma}} \qquad (1)$$

Demand for semiconductors from location *i* is written in equation (2), where *k* represents total expenditures:

$$q_i = \; k \, b_i \; P^{\sigma-1} p_i^{\;-\sigma} \qquad (2)$$

[50] We use the term "consumers" loosely in this section, but it should be interpreted as the U.S. purchaser of the semiconductor and not as the final consumer of a final good.

Supply for each location of manufacturing is represented by a supply curve, with constant price elasticity of supply ($\varepsilon_i$) and supply constant $a_i$:

$$q_i = a_i \, p_i^{\varepsilon_i} \qquad (3)$$

An important attribute of the semiconductor industry is that in the short run, it is very difficult to increase fabrication capacity due to the complexity of the manufacturing process. Therefore, capacity constraints are added as asymptotes to each country's supply curve by augmenting equation (3) to the following:

$$q_i = \overline{q_i} - a_i \, p_i^{-\varepsilon_i} \qquad (4)$$

where $\overline{q_i}$ represents practical capacity of supply for each country modeled. Capacity data is generally not available by country and segment, so information about major producer's capacity utilization is used to estimate the capacity constraint. More information about capacity utilization can be found in the data and parameter inputs section below.

U.S. imports of semiconductors that were manufactured in Taiwan are exogenous in the model and reduced in five percent increments to illustrate the sensitivity of model outcomes to different scenarios of the hypothetical manufacturing disruption in Taiwan. Regardless of what may be the potential cause of the shock, the model simply estimates the response in U.S. prices and quantities to a range of shock values—the various levels of reduction in Taiwan semiconductor output. Doing so allows us to illustrate the levels of sensitivity of the U.S. semiconductor market corresponding to the levels of severity in the hypothetical manufacturing disruption in Taiwan.

This modeling exercise and analysis are conducted in two stages. At the first stage, a simplified, aggregate PE model (hereafter, aggregated model) is used to estimate the sensitivity in U.S. prices and quantities. This first model is more conventional, treating the entire semiconductor industry as homogenous, and the import sources as the indication of production site. Therefore, the modeling exercise at the first stage does not make supply chain related tracing and trade adjustment, and also does not require the splitting of HTS codes. The benefit of using this aggregate, conventional model is that it requires less data and assumptions, and there are sufficient data for the estimation of substitution elasticities. Although simplified, it serves as a benchmark estimate to compare with segment-specific effects in the second-stage analysis.

At the second stage, a more disaggregated model (hereafter, segmented model) with global supply chain features is used. The model breaks down the semiconductor industry into three segments: logic chips, memory chips, and analog chips. The shares of U.S. imports of each segment by the original manufacturing economy are estimated using the supply chain tracing technique described above. The model also disaggregates U.S. imports of each segment by five major sourcing locations: Taiwan-manufactured, Korean-manufactured, Japanese-manufactured, Chinese-manufactured, and ROW-manufactured. This model allows us to disentangle trade flows along global supply chains, take into account the segment specialization of major producing economies, and separately estimate distinct impacts by segment and sourcing economy.

Data inputs, parameter estimations, and result analyses for these two stages of modeling exercises are described below.

## Data Inputs and Parameter Estimations

### Inputs of the Aggregated Model in Stage One

U.S. domestic production of semiconductors competes with U.S. imports of substitutable products. For the aggregate model, domestic production data were obtained from the U.S. Annual Survey of Manufactures for NAICS codes 334413 and 334418.[51] U.S. imports and exports data were obtained from USITC's DataWeb for HTS codes 8542 and 8473.30.11.[52] Exports are subtracted from domestic production to arrive at the value of domestically-produced semiconductors that are consumed in the U.S. market. See table 3 for a list of data inputs in the aggregate model.

As described above, the share of U.S. imports sourced directly from Taiwan in the trade statistics most likely does not reflect the true share of imports that were manufactured in Taiwan for a couple of reasons. Taiwan-manufactured semiconductors may be sent to a third country for ATP before exporting to the United States. Since U.S. customs data reports the semiconductor shipment entering the United States from the last point of departure (the third country), Taiwan share could be under-reported in this type of trade flow. On the other hand, Taiwan also provides ATP services to non-Taiwan manufactured chips before exporting them directly to the United States. Thus, Taiwan share could be over-reported in this type of trade flow.

To overcome these data limitations, we estimate a lower and upper bound on the share of U.S. semiconductor imports that were manufactured in Taiwan. The lower bound is the share of semiconductors imported directly from Taiwan based on the U.S. imports data. The upper bound is the share of Taiwan semiconductor industry output in global semiconductor sales. This assumption would imply that the share of Taiwan-manufactured chips in U.S. imports is reflective of the global share of Taiwan production. The assumption implies frictionless markets, where there are no supply chain rigidities that cause one country to have a different share than another country and is used as an upper bound in the analysis. In the first modeling exercise, we generate results under the lower- and upper-bound assumptions to produce a range of possible outcomes.

[51] U.S. Census Bureau, Annual Survey of Manufactures (ASM), accessed October 12, 2023.

[52] USITC, DataWeb, accessed October 12, 2023. The HTS code 8473.30.11 includes both logic (GPUs) and analog semiconductors, as well as some printed circuit board products that may be outside the scope of this analysis. An area of future research is to better understand the proportion of HTS 8473.30.11 that should be excluded from U.S. imports.

**Table 3** Model inputs of the aggregate model in the first stage analysis

| Variable | Aggregate Value (2021) | Source |
|---|---|---|
| U.S. domestic production | $80.43 billion | U.S. Annual Survey of Manufactures, NAICS codes 334413 and 334418 |
| U.S. imports | $62.05 billion | USITC's DataWeb, HTS 8542 and 8473.30.11 |
| U.S. exports | $28.31 billion | USITC's DataWeb, HTS 8542 and 8473.30.11 |
| Estimated share of U.S. imports that were manufactured in Taiwan | Lower bound: 19.3%<br>Upper bound, SIA: 24.6% | Lower bound is Taiwan's share in U.S. imports, calculated based on U.S. import data from USITC's DataWeb; upper bound is estimated with global sales data from SIA 2022 Factbook as well as Taiwan semiconductor industry output in a newsletter published by Taiwan Semiconductor association. |
| Elasticity of substitution | 3.32 | Estimated using the markup method from Ahmad and Riker (2019) |
| Price elasticity of supply, U.S. production | 2.00 | Estimated using capacity utilization data and information about technology |
| Price elasticity of supply, RoW (non-Taiwan manufactured) | 3.00 | Estimated using capacity utilization data and information about technology |

There are two elasticities in the aggregate model: the elasticity of substitution and the price elasticity of supply. The elasticity of substitution describes how U.S. purchasers substitute between the different varieties of a product after a relative price change. This elasticity was estimated using the markup method described in Ahmad and Riker (2019).[53] As seen in table 3, the elasticity is estimated as 3.32, a low/medium range estimate.[54] This low/medium elasticity estimate appears to fit well with the industry, as many semiconductor products are customized, requiring specialized inputs to produce the specific type of chips needed for each downstream segment. It is generally difficult to change sources given the length of time and specialization required, both for advanced logic chips as well as the less advanced analog chips that are more commonly used in automobile manufacturing.[55]

[53] Ahmad and Riker, "A Method for Estimating the Elasticity of Substitution and Import Sensitivity by Industry," May 2019.
[54] We also considered econometrically estimating the elasticity of substitution with the trade cost method described in Riker (2020). However, that method uses U.S. import data and a calculated trade cost measure and would estimate the elasticity based on switching testing and packaging locations, not on changing manufacturing locations. Because of this, we used the markup method that does not rely on trade data. Riker, "A Trade Cost Approach to Estimating the Elasticity of Substitution," July 2020.
[55] SIA, *Impact of the Global Semiconductor Shortage on the U.S. Communications Sector*, June 10, 2021.

The second group of elasticities is the price elasticity of supply for each source (U.S. domestic production, non-Taiwan manufactured imports).[56] This elasticity is estimated using information about capacity utilization, availability of production technology, and length of time required to change production levels by source. In the aggregate model, the price elasticity of supply for U.S. production was estimated to be a value of 2 and the non-Taiwan imports source price elasticity of supply was estimated to be a value of 3. Low values are assigned because the time frame of the model is considered to be relatively short-run, producers on average are nearing full practical capacity, and it is costly (both in terms of money and time required) to bring on new capacity in a short run. In addition to the low price elasticity of supply estimates, the supply curves have an asymptotic capacity constraint, based on the information about capacity utilization. For aggregate U.S. supply of semiconductors, we use utilization data from the Federal Reserve Bank of St. Louis (FRED), showing capacity utilization between 71 and 88 percent since January 2021.[57] This capacity utilization estimate is also supported by a recent SIA report that states that fabrication typically can run above 80 percent capacity utilization during periods of high market demand.[58]

### Inputs of the Segmented Model in Stage Two

Turning to the second modeling analysis, the segmented models require additional data inputs and estimation to arrive at the set of inputs required in each segment model. First, supply is divided into six differentiated varieties: U.S. produced chips that are consumed in the U.S., U.S. imports of Taiwan-manufactured chips, U.S. imports of Korean-manufactured chips, U.S. imports of Chinese-manufactured chips, U.S. imports of Japanese-manufactured chips, and U.S. imports of chips manufactured in the rest of the world. Data on domestic production of memory, logic, and analog segments are not readily available, and thus are estimated using global fabrication capacity shares from CRS report together with global sales data from SIA factbook. Total U.S. imports and domestic exports are obtained from USITC's DataWeb and adjusted to remove the "round trip" trade, i.e., U.S.-produced chips that are exported and re-imported. The shares of imports by segment that are manufactured in Taiwan, South Korea, China, Japan, and ROW are estimated using a supply chain tracing technique described in detail in the section above titled "U.S. Exposure to Taiwan Semiconductor Industry." See table 4 for model inputs in each segmented model.

[56] Note that a price elasticity of supply is not needed for Taiwan-manufactured semiconductors, as they are treated as exogenous in the analysis.
[57] Federal Reserve, "Capacity Utilization," accessed October 2, 2023.
[58] SIA, *Impact of the Global Semiconductor Shortage on the U.S. Communications Sector*, June 10, 2021.

**Table 4** Model inputs of the segmented models in the second stage of analysis

| Variable | Memory Segment | Logic Segment | Analog Segment | Source |
|---|---|---|---|---|
| U.S. domestic production | $7.69 billion | $30.19 billion | $20.01 billion | Estimated using data from the CRS 2023 report and SIA 2022 Factbook |
| U.S. imports | $2.16 billion | $42.57 billion | $10.96 billion | USITC's DataWeb with adjustments |
| U.S. exports | $1.23 billion | $11.78 billion | $7.99 billion | USITC's DataWeb with adjustments |
| Estimated share of U.S. imports manufactured in Taiwan | 24% | 44% | 1% | See U.S. Exposure section above |
| Estimated share of U.S. imports manufactured in South Korea | 30% | 15% | 12% | See U.S. Exposure section above |
| Estimated share of U.S. imports manufactured in China | 19% | 17% | 6% | See U.S. Exposure section above |
| Estimated share of U.S. imports manufactured in Japan | 13% | 4% | 11% | See U.S. Exposure section above |
| Estimated share of U.S. imports manufactured in ROW | 14% | 19% | 69% | See U.S. Exposure section above |
| Elasticity of substitution | 3.32 | 2.32 | 4.32 | Estimated using the markup method from Ahmad and Riker (2019) with adjustments |

Notes: The HTS code for memory chips is 8542.32. The HTS codes for logic and analog chips are 8473.30.11, 8542.31, and 8542.39. U.S. imports and exports are adjusted to account for U.S. production of semiconductors that were exported and re-imported.

The elasticities in the segmented modeling analyses are estimated differently than in the aggregate model. The elasticity of substitution is anchored on the aggregate elasticity (3.32) and adjusted higher or lower for each segment based on qualitative information about consumer preferences, product differentiation, and ease of switching manufacturing locations. The logic elasticity of substitution is reduced to reflect the difficulty in switching manufacturing locations due to the customization of products for different downstream users and the concentration of logic chip manufacturers. In one subset of the logic segment, advanced logic chips, Taiwan supplies over 90 percent of the market so it may be difficult for a U.S. purchaser to find a replacement.[59] The elasticity of substitution for the analog

[59] BCG and SIA, *Strengthening the Global Semiconductor Supply Chain in an Uncertain Era*, April 2021.

segment, on the other hand, is revised higher as they are typically made with older processing techniques and have more available supplier choices for U.S. purchasers.

The calibrated supply curve for each segment and each manufacturing source (U.S., South Korea, China, Japan and ROW) is upward sloping, with a constant elasticity of supply and an asymptotic capacity constraint. As in the aggregate model above, this capacity constraint improves the accuracy of the model results as in the short run, it is difficult for many of the suppliers to increase fabrication capacity for certain segments. We estimate capacity utilization by segment for each region using anecdotal information on the largest producers for each country modeled. Most countries and segments are facing some degree of capacity constraint, except Samsung—one of the largest manufacturers of memory chips—who reported lower capacity utilization in 2023 due to decreased sales in the memory segment.[60]

## Modeling Results

### Results from the Aggregated Model in Stage One

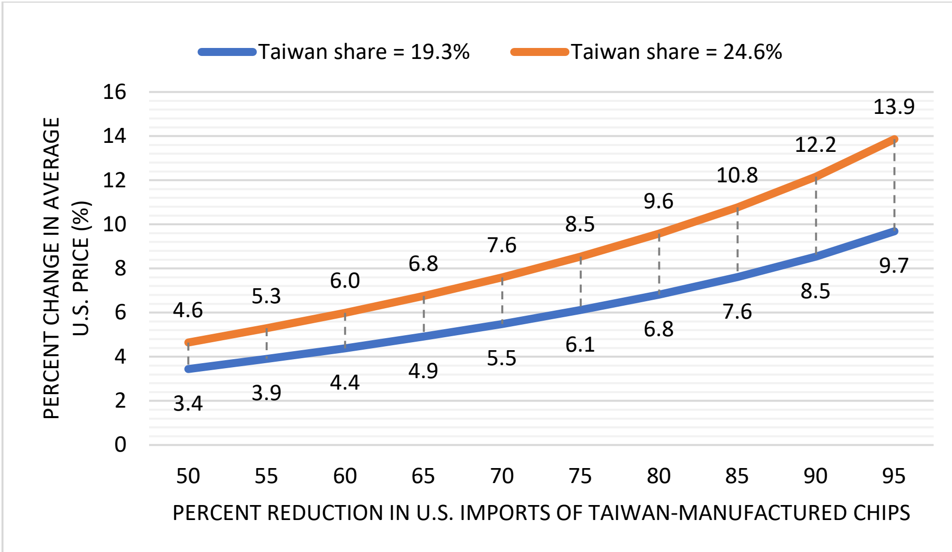
The aggregated model uses the data inputs and parameter estimates described above, as well as the assumed functional forms, to calibrate the baseline. The modeling exercise applied a hypothetical shock to Taiwan manufacturing that reduces U.S. imports of Taiwan-manufactured semiconductors by a range of 50–95 percent, with 5 percent increments between. The model estimated the economic effect of this series of U.S. import reductions from Taiwan on semiconductor prices and quantities in the United States. Instead of estimating the specific impact of a disruption on Taiwanese manufacturing, we are showing the sensitivity of U.S. prices and quantities under various depth of disruptions.

A reduction in U.S. imports of Taiwan-manufactured chips, a left shift in the supply curve of Taiwan-manufactured chips, would lead to a shift in demand to non-Taiwan sources as consumers of chips look elsewhere for their production inputs. This would increase demand for U.S.-manufactured, Korean-manufactured, Chinese-manufactured, Japanese-manufactured and ROW-manufactured chips, subject to their respective capacity constraints. Prices will likely increase for all products, and downstream chip users will face reduced total supply of chips. The modeling exercise estimated the percentage changes in prices and quantities of each source as a result of the Taiwan supply disruption, as well as the dollar value change in shipments of each source. The magnitude of the impacts is affected by the market shares of each source of supply, the estimated elasticities, and the size of the shock.

Figures below show the range of modeled outcomes under different assumptions about the Taiwan production shock. A 75 percent reduction in U.S. imports of Taiwan-manufactured chips, for example, is estimated to increase the average U.S. price that downstream users would pay for semiconductors by about 6.1–8.5 percent (figure 11). This same 75 percent reduction in U.S. imports of Taiwan-manufactured chips is estimated to also increase U.S. domestic production of semiconductors by about 3.6–4.3 percent (figure 12). As downstream users of semiconductors experience a significant increase in prices, they likely reduce output for products that rely on semiconductors as inputs.

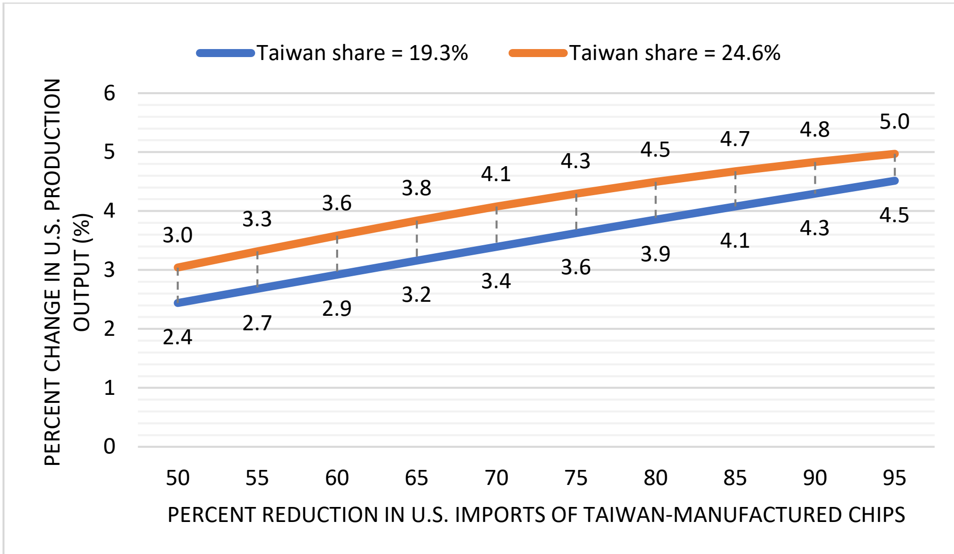
[60] Chang, "Korean OSAT Players See Utilization Falling below 50%," August 2, 2023; Bouchaud, "Analog Chips – Poised to Become the next Big Threat to Automakers?," January 27, 2022.

**Figure 11** Estimated percent increase in average U.S. price of semiconductors after a Taiwanese semiconductor manufacturing disruption, by percent reduction in imports of Taiwanese-manufactured chips




Notes: The U.S. average price is a weighted average of the import and domestic prices of semiconductors that downstream producers pay. The blue line represents modeled outcomes under the assumption that the Taiwanese share of U.S. imports is 19.3%, the actual share of imports directly sourced from Taiwan. The orange line represented modeled outcomes under the assumption that the Taiwanese share of U.S. imports is 24.6%, the estimated share of U.S. imports that were manufactured in Taiwan. The region between the two lines can be interpreted as the region of likely outcomes after an X percent reduction in U.S. imports from Taiwan.

**Figure 12** Estimated percent increase in U.S. production output of semiconductors after a Taiwanese semiconductor manufacturing disruption, by percent reduction in imports of Taiwanese-manufactured chips




Notes: The blue line represents modeled outcomes under the assumption that the Taiwanese share of U.S. imports is 19.3%, the actual share of imports directly sourced from Taiwan. The orange line represented modeled outcomes under the assumption that the Taiwanese share of U.S. imports is 24.6%, the estimated share of U.S. imports that were manufactured in Taiwan. The region between the two lines can be interpreted as the region of likely outcomes after an X percent reduction in U.S. imports from Taiwan.

These estimates may appear to be small relative to the importance of Taiwan in the global semiconductor supply chain. It is important to note that the effects are watered down by the segments where Taiwan does not play a big role; for example, the analog chip segment. In the second modeling analysis below, segments are modeled separately and economic impacts for certain segments are much larger than this average effect.

It is important to note that we are only estimating the direct impact of a disruption on imports of semiconductor chips. This modeling analysis is a lower bound: we do not estimate the impact on chips entering the U.S. already installed in a downstream product. Including imports of downstream products in the analysis would significantly increase the estimated effects. We are also measuring the average effect across segments and across downstream users. We are not measuring an individual (and potentially catastrophic) impact on specific downstream producers, like the medical device industry. We can better understand the impacts for specific downstream users by looking at the segment-specific effects below.

### Results from the Segmented Models in Stage Two

This section reports modeling results for each of the three semiconductor segments. The logic chip segment experiences the largest price increases—as high as 58.6 percent. In comparison, the price increases in memory chip and analog chip segments are relatively small, under 5 percent (figure 13). Several factors may contribute to such a large impact on the logic chip segment. Taiwan accounted for the largest share–31 percent of U.S. consumption of logic chips. Any substantial reductions in U.S.

imports of logic chips from Taiwan would affect the total supply notably. On the other hand, the increase in U.S. domestic production is constrained due to the near "full" capacity. As a result, the percentage changes in the quantity of U.S. logic chip production taper off even as the magnitude of the Taiwan shock increases (figure 14). These domestic supply constraints lead to larger price effects on logic chips for downstream users.

Similarly, compared to memory and analog chip segments, the logic chip segment also experiences the largest increase in domestic sales of U.S. products in terms of dollar value, due to the combination of price and quantity effects (figure 15). This clearly illustrates that the impact of a major Taiwan manufacturing disruption is not uniform across segments.

**Figure 13** Estimated percent increase in average U.S. price of semiconductors after a Taiwanese semiconductor manufacturing disruption, by segment

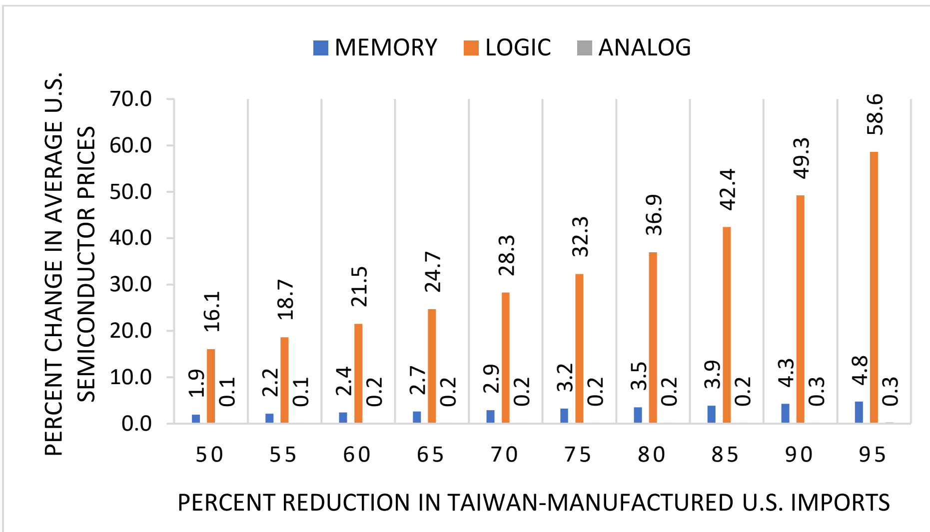



**Figure 14** Estimated percent increase in U.S. production output of semiconductors after a Taiwanese semiconductor manufacturing disruption, by segment

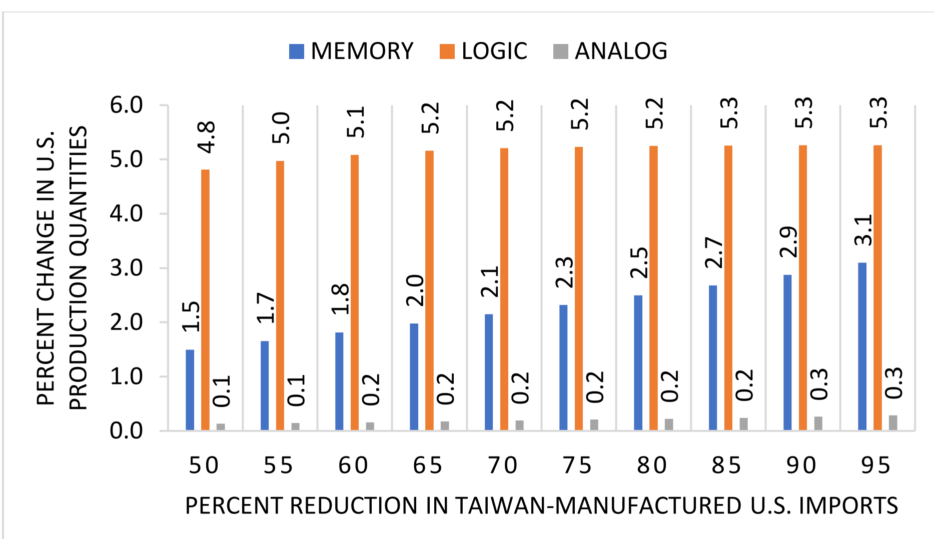
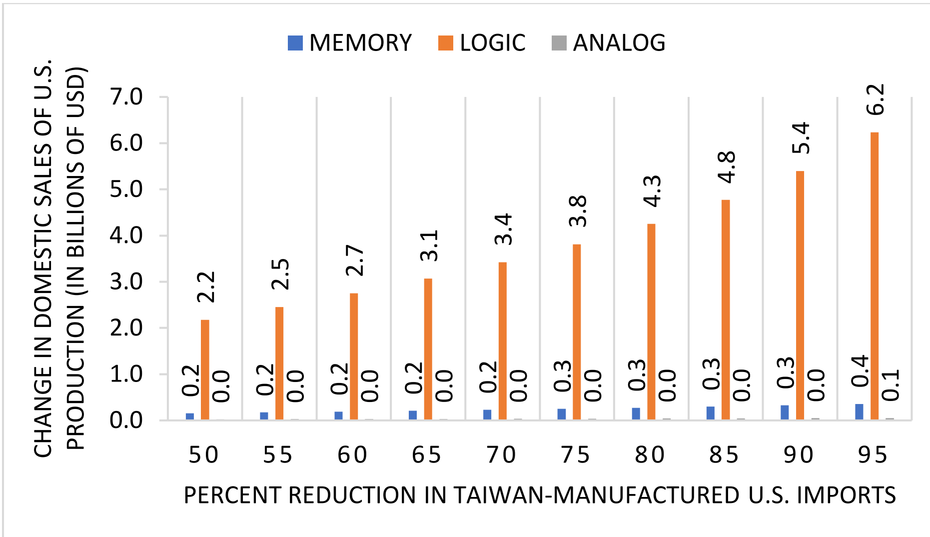


**Figure 15** Estimated dollar value changes in U.S. production of semiconductors after a Taiwanese semiconductor manufacturing disruption




Although non-Taiwan producers increase their U.S. sales of semiconductors in terms of dollar value, the impacts are also not uniform (figure 16, 17 and 18). Overall, compared to South Korea, China, and Japan, U.S. producers capture the largest sales increases across all three segments. However, for all non-Taiwan producers, the changes in sales value are most significant in the logic chip segment—U.S. producers increase sales by a range of $2.2–$6.2 billion, while China and South Korea increase their U.S. sales with a smaller range of $0.8–$2.2 billion (figure 16). As described earlier, much of this dollar value change is from a sharp increase in prices instead of a sizeable increase in quantities. It is also worth noting that the results illustrated here is an average effect across different types of logic chips with different technology nods. As South Korea is the primary competitor of the most advanced logic chips that Taiwan produces, a larger shift in trade from Taiwan to South Korea can potentially occur yet is not fully captured in this modeling exercise.[61] With respect to China, the results likely reflect increased U.S. sales of legacy logic chips (not the advanced chips), which the United States typically imports from China.[62]

[61] BCG and SIA, *Strengthening the Global Semiconductor Supply Chain in an Uncertain Era*, April 2021, 35.
[62] Shivakumar, Wessner, and Howell, *The Strategic Importance of Legacy Chips*, March 2023, 5–7; BCG and SIA, *Strengthening the Global Semiconductor Supply Chain in an Uncertain Era*, April 2021, 35.

**Figure 16** Estimated dollar value changes in U.S. sales by manufacturing country and segment after a Taiwanese semiconductor manufacturing disruption, logic chips segment

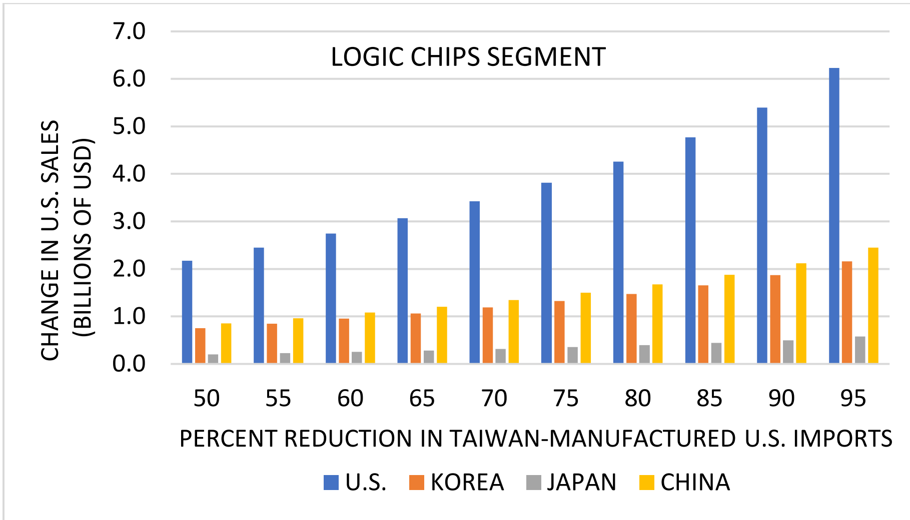



**Figure 17** Estimated dollar value changes in U.S. sales by manufacturing country and segment after a Taiwanese semiconductor manufacturing disruption, analog chips segment

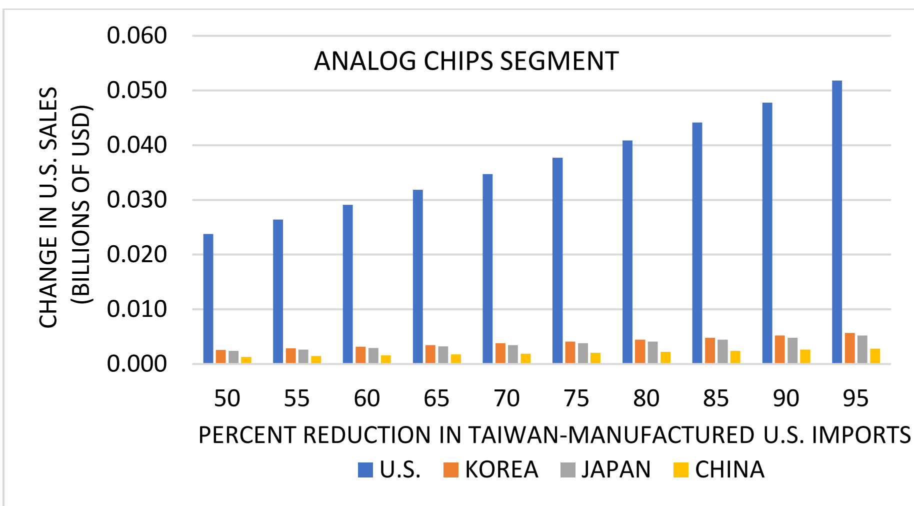
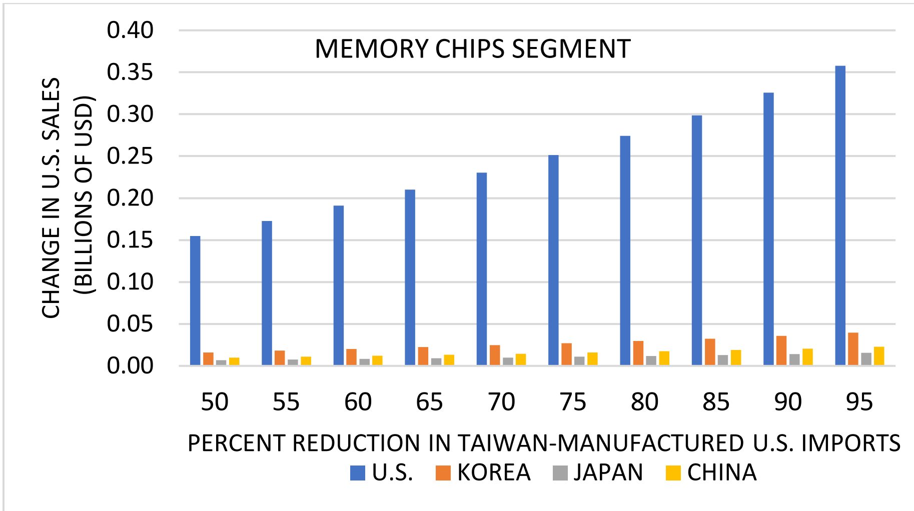


**Figure 18** Estimated dollar value changes in U.S. sales by manufacturing country and segment after a Taiwanese semiconductor manufacturing disruption, memory chips segment



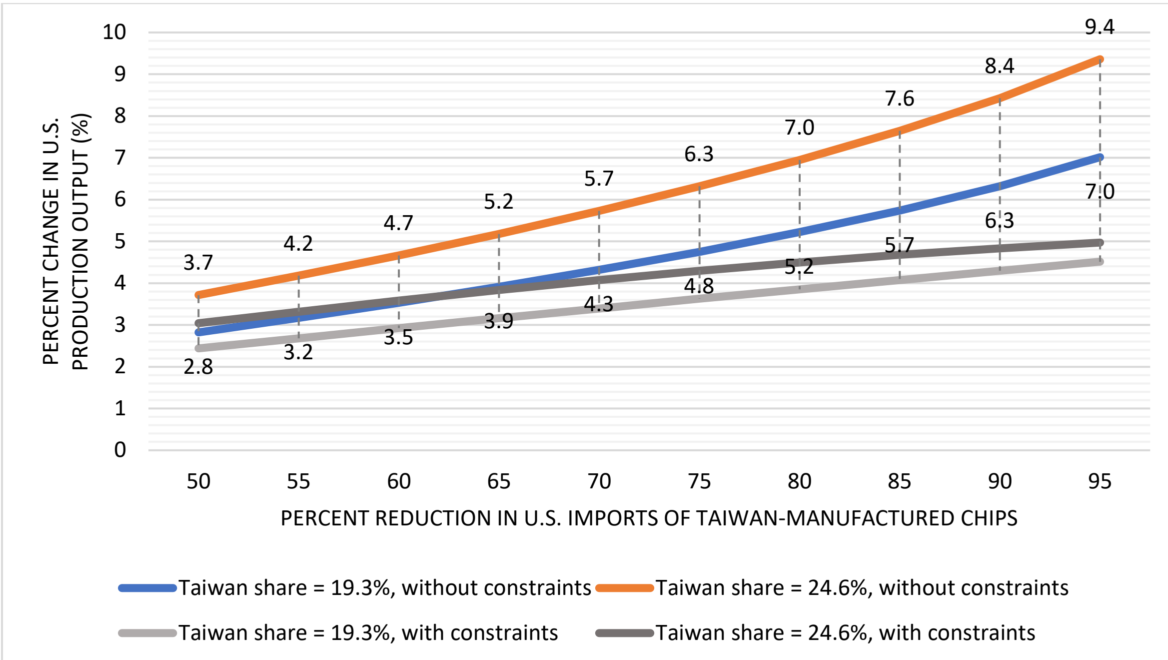

## Counterfactual without Domestic Supply Constraints

The modeling analysis presented above assumes that U.S. firms are generally constrained in their manufacturing capacity, as in the past several years, the average capacity utilization is near the practical full capacity (80 percent).[63] In this section, we consider a counterfactual scenario where additional capacity is brought on in the United States. This is especially relevant because the recent CHIPS Act, described in an earlier section, is intended to bring additional U.S. capacity online in the near future.[64] It is important to note that we do not estimate the amount of new capacity brought online in the United States due to the CHIPS Act, we simply remove the capacity constraint for U.S. manufacturing in the model and simulate a new market equilibrium absent the constraint. However, the capacity constraints for the other manufacturing economies remain.

First, results from the aggregate model are shown in figure 19. The grey lines on the graph are identical to figure 12 above with domestic capacity constraints, in which the percentage changes of U.S. production increase as high as 5.0 percent. The blue and orange lines display U.S. production with no capacity constraint in place, in which the percentage changes of U.S. production rise as high as 9.4 percent.

[63] Note that there are differences in capacity utilization by segment and firm. The 80 percent estimate is an industry average estimate. SIA, *Impact of the Global Semiconductor Shortage on the U.S. Communications Sector*, June 10, 2021.
[64] For more information about the CHIPS Act, see the section above titled "U.S. CHIPS and Science Act". White House, "FACT SHEET: CHIPS and Science Act Will Lower Costs," August 9, 2022.

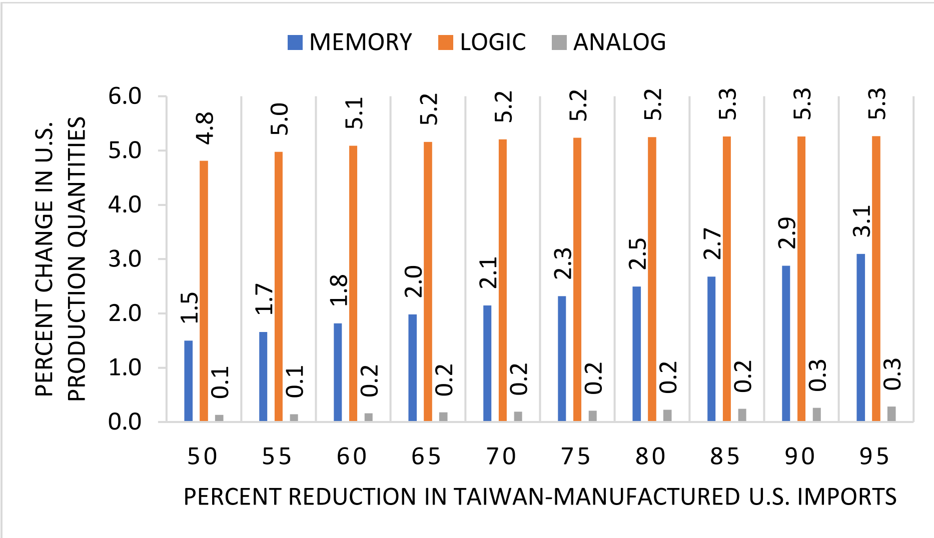
**Figure 19** Estimated percent increase in aggregate U.S. production output, with and without domestic capacity constraints



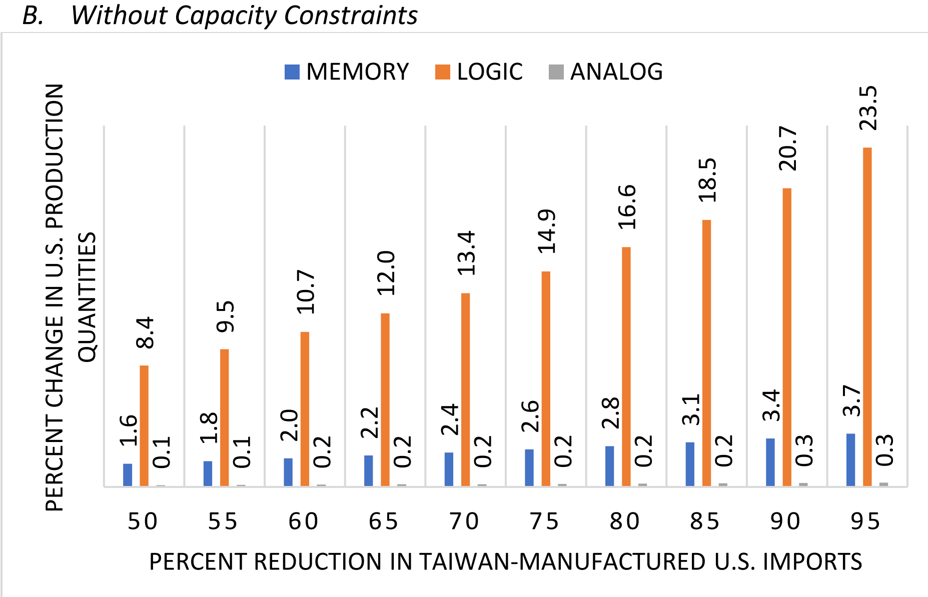

The segmented model results are shown in figure 20 below. The graph A is identical to figure 14 above with capacity constraints, in which the percentage changes in the quantity of U.S. production level off at 5.3 percent for the logic chip segment. The graph B shows the segmented model results with no U.S. capacity constraint, in which the percentage changes in the quantity of U.S. production increase as high as 23.5 percent. With these two graphs, it is evident that the logic chip segment has the most to gain from an unconstrained supply. Comparatively, there are no substantial differences in the analog and memory chip segments. In the model simulation, those two segments are not reaching their practical capacity constraint. Thus, removing the U.S. constraints does not make a big difference on these two segments.

**Figure 20** Estimated percent increase in U.S. production output by segment, with and without capacity constraints

*A. With Capacity Constraints*




*B. Without Capacity Constraints*




## V. Conclusions

This paper attempts to estimate the U.S. exposure and sensitivity to a hypothetical Taiwanese manufacturing disruption to understand the level of U.S. vulnerability in terms of relying on Taiwan-manufactured semiconductor products. To do so, first, we use a global supply chain tracing technique to estimate U.S. exposure to Taiwan semiconductor industry—the share of U.S. semiconductor imports that are originally manufactured in Taiwan. This is crucial because the last stop before the import shipments arrive at the U.S. border often are the locations where ATP services are provided, instead of the manufacturing sites. We estimate that 44.2 percent of U.S. imports of logic chips were manufactured in Taiwan, compared to 24.4 percent of U.S. imports of memory chips and 1.0 percent of U.S. imports of analog chips.

Then, we use the estimated shares to model the sensitivity of U.S. market prices and quantities to a hypothetical Taiwanese manufacturing disruption at the segment level. The modeling results show that the U.S. logic chip segment would experience the largest negative impacts, leading to as high as a 59 percent increase in prices that U.S. downstream producers will pay. The model estimates that U.S. producers of logic chips can only partially replace the lost imports due to current capacity constraints, as they can increase domestic production of logic chips by only as high as 5 percent.

This analysis could be improved with better data. In particular, a more precise estimate of U.S. exposure could be attained if U.S. import statistics include information about the manufacturing (wafer fabrication) locations. In addition, the HTS needs more granular delineation to match different semiconductor segments. With more detail on the types of semiconductors imported into the United States, we potentially could further disaggregate the PE model to narrow in on the specific types of advanced logic chips at different node sizes that would be most impacted by a hypothetical disruption in Taiwanese manufacturing.

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